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Catarina Brandão Teixeira

Methodologies for environmental aspects assessment

Metodologias de avaliação de aspetos ambientais

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Gestão e Políticas Ambientais, realizada sob a orientação científica da Doutora Maria Helena Gomes de Almeida Gonçalves Nadais, Professora Auxiliar do Departamento de Ambiente e Ordenamento da Universidade de Aveiro, e coorientação da Doutora Ana Cláudia Relvas Vieira Dias, Equiparada a Investigadora Auxiliar do Departamento de Ambiente e Ordenamento da Universidade de Aveiro.

O júri

Presidente	Prof.ª Doutora Myriam Alexandra dos Santos Batalha Dias Nunes Lopes Professora Auxiliar do Departamento de Ambiente e Ordenamento da Universidade de Aveiro. (**Presidente**)
	Prof. Doutor António José Dinis Ferreira Professor adjunto da Escola Superior Agrária de Coimbra (ESAC). (**Arguente**)
	Prof.ª Doutora Maria Helena Gomes de Almeida Gonçalves Nadais Professora Auxiliar do Departamento de Ambiente e Ordenamento da Universidade de Aveiro. (**Orientadora**)

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Palavras-chave

Aspetos ambientais; Avaliação de ciclo de vida; ISO 14001; Metodologias de avaliação

Resumo

Nos últimos anos, a consciência ambiental e, consequentemente, a necessidade de proteção ambiental despoletaram o crescimento e desenvolvimento das normas e regulações ambientais, como é exemplo a ISO14001. Em 2015, surgiu, então, uma versão atualizada da referida norma (ISO14001:2015), que passa a recomendar que as metodologias de avaliação de aspetos ambientais sejam desenvolvidas tendo em conta a perspetiva de ciclo de vida – sendo esta uma das fases mais complexas de gerir aquando de uma certificação ambiental.

O presente estudo foi realizado numa indústria de pneus onde, de acordo com as atividades, serviços e produtos da mesma, foi desenvolvida e proposta uma metodologia baseada em avaliação de ciclo de vida, com o intuito de se realizar uma análise comparativa com o método qualitativo/semiquantitativo atualmente aplicado, permitindo, então, determinar qual a mais eficiente de acordo com as necessidades da organização.

Em última análise, a metodologia proposta ao longo do estudo combina um método quantitativo, baseado em avaliação de ciclo de vida, com um método qualitativo, baseado em requisitos legais e perspetiva de partes interessadas e, inclui, ainda, uma análise de risco. Desta maneira, garante a avaliação de todos os *inputs* e *outputs* relacionados com o ciclo de vida do pneu. Assim, a presente proposta fornece um método *standard*, cientificamente aceite e que se mostra capaz de obter resultados fidedignos e reprodutíveis. Para além disso, este método diminui a subjetividade inerente à maior parte das metodologias que têm vindo a ser adotadas pelas organizações, assim como aumenta o foco do impacte ambiental associado aos referidos aspectos. De acordo com os pontos acima mencionados, a metodologia sugerida pode ser considerada uma boa opção para ser aplicada em qualquer tipo de organização.

Keywords

Assessment methodologies; Environmental aspects; ISO 14001; Life Cycle Assessment

Abstract

Environmental increasing awareness and the demand for environmental protection fed the need for the development of internationally recognized standards and regulations, such as ISO 14001. The new version of the present standard emerges on 2015 (ISO 14001:2015), including the recommendation of using life cycle thinking perspective upon the assessment of the organization's environmental aspects – considered so far one of the most difficult phases to accomplish amongst the environmental certification.

The present study takes place on a tire manufacturing industry where a LCA-based methodology is to be developed and proposed - according to the collected data about their activities, services and products - in order to stress its efficiency, in opposition to the already qualitative/semi-quantitative methodology applied on the organization.

Ultimately, the proposed methodology of the present study combines a LCA-based quantitative assessment, a qualitative assessment (concerning legal compliance and stakeholder's perspective) and a risk degree analysis. This combination guarantees the evaluation of the whole framework of inputs and outputs related to the life cycle of a tire. It seeks to provide a standardized and scientifically accepted method, able to reach reliable, stringent and reproducible results. Indeed, it is effective on lowering the subjectivity inherent to the majority of the assessments currently applied on environmental aspects assessment, as well as raising the environmental relevance assigned to those aspects. For all this reasons, the suggested methodology under study might be a suitable option for the present organization, as well as for other companies to adopt.

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1. Introduction

1.1. Contextualization

The human capacity for production and development of the basics, necessary to their survival and constant needs, has been evolving for years - since their efforts to develop material, by their own hands, to hunt and feed themselves, to the enormous amount of companies and their machines capable of developing any kind of technology (phones, televisions, wash-machines, among the plethora of technologies that we use in our everyday). During the XVIII century, the world has suffered a rapid urbanization, together with an explosive scientific and technologic development, also known as the industrial revolution. This evolution into a much greater production capacity had, on the one hand, enhanced the economics, and on the other hand, led to deep modifications on the environment. Examples of those modifications include the amount of environmental disasters which marked that time (for instance, in 1956 the Minamata disease case and in 1986 the Chernobyl accident). These stated events awakened in the society a sense of concern with the continuous growth of the worldwide pollution and, consequently, their future destination. Thereby, the beginning of the 70's was marked by the gain of environmental consciousness and the appearance of the first conferences, treaties and actual actions regarding the environmental protection (Reinaldo Dias, 2007).

Industrial processes are usually associated with significant environmental impacts, mostly due to emissions release, consumption of natural resources, waste generation and, ultimately, due to potential irreversible damage that can be caused in the ecosystem – human health, climate change, biodiversity, among others. Hence, environmental awareness and the need for environmental protection have had a significant growth, leading to the development of internationally recognized standards and regulations (Ljubas and Sabol, 2011). In this context, organizations have been suffering pressure from stringent environmental laws and a more demanding society (Tourais and Videira, 2016). Therefore, in order to adapt to these pressures, they have started to look for a way to achieve an environmental certification, by implementing an Environmental Management System (EMS) that integrates the environmental dimension within the existing management structure (Marazza *et al*., 2010).

A certified EMS requires the commitment of the organization on improving its environmental management and performance continually, through the implementation of an environmental policy, including their environmental aspects, goals and management programmes (ISO 14004, 2004; Ardente *et al*., 2006; Zobel, 2008). The overall objective is to help the organization identifying, managing, monitoring and controlling their environmental issues in a holistic perspective (ISO, 2015). The requirements for implementing an EMS are pre-set by an international agreed standard (ISO14001) and by the Eco-Management and Audit Scheme (EMAS) (União Europeia, 2009; IPQ, 2015). The former is recognised and accepted worldwide, whereas the latter is only recognised in the European Union. Both are considered voluntary standards, with similar specifications, which allows the company's environmental certification, signalling the properly implementation of the EMS (Burke and Gaughran, 2006; Zobel, 2008; ISO, 2015; Tourais and Videira, 2016).

An EMS is based on a Deming cycle methodology, also known as PDCA cycle: Plan-Do-Check-Act (Figure 1). The *Plan* phase includes the definition of the environmental policy together with environmental goals and targets, allowing planning the activities according to the pre-set priorities. The *Do* phase is represented by the implementation of the planned activities in the previous phase. The *Check* phase reflects the verification of the results and, finally, the *Act* phase, is where a revision is made upon pre-set priorities, environmental goals, targets and policies - executed using environmental performance indicators. Thus, the cycle is repeated, so that the organization, by implementing an EMS, may accomplish a continuous improvement over time (Lundberg *et al*., 2007; Edalat, 2008; Seiffert, 2008; Zobel, 2008; Marazza *et al*., 2010; Petrosillo *et al*., 2012; IPQ, 2015).

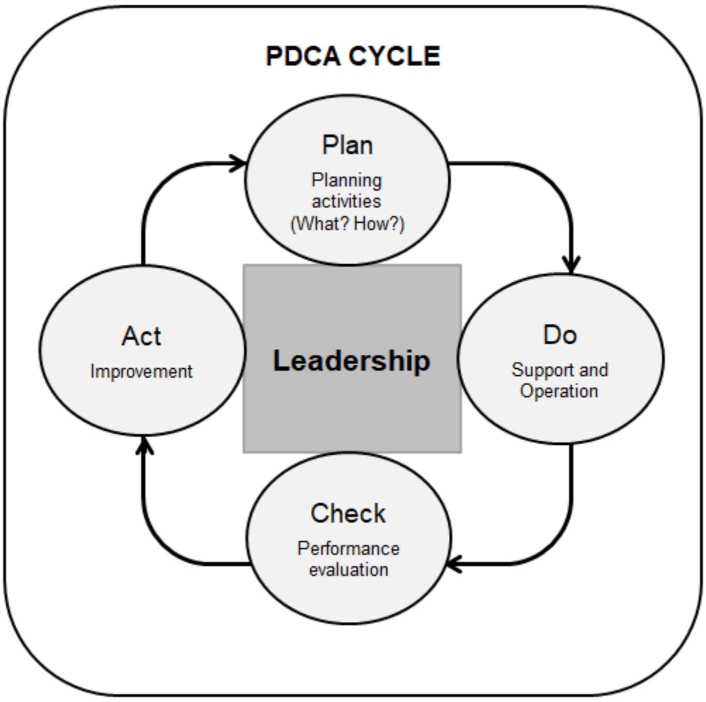


Figure 1. Illustration of PDCA cycle. Source: IPQ (2015).

According to ISO 14001 and also stressed by Seiffert (2008) and Zobel (2008), during the planning phase, firstly it should be made an identification of relevant laws, legal requirements and environmental procedures. Then, it should be performed the assessment of environmental aspects, regarding their significance and, finally, it is necessary to establish the environmental policy, regarding the organizations' priorities (IPQ, 2015). Tourais and Videira (2016) underlined that environmental policies developed after the initial environmental review, that is, after knowing which environmental aspects need prioritization, tend to include more specific commitments and environmental objectives.

Regrettably, implementing an EMS is not quite easy and organizations that seek for an environmental certification face some difficulties such as lack of time, human resources, skills and competencies, as well as achieving staff involvement and motivation. They also have to deal with budget constraint, since the EMS has to compete with many other priorities of the company and, sometimes, with technical difficulties in understanding and implementing EMS requirements. Furthermore, they might face barriers on the initial registration, mainly with registration costs and difficulties in achieving and maintaining legal compliance (Gernuks *et al.,* 2007; Testa *et al*., 2011). Nevertheless, the most complex phase to accomplish is the assessment of environmental aspects, since the standard does not provide a specific and more correct methodology for assessing the significance of environmental aspects, only some general guidelines of what is intended (Põder, 2006; Gernuks *et al.,* 2007; Lundberg *et al*., 2007; Joachimiak-Lechman, 2013). This stage is crucial, inasmuch as it allows formulating an environmental policy with the setting environmental objectives and targets, ensuring the prioritization of organizations' environmental problems, which represent the background of the whole environmental management system, therefore enabling the organizations' continuous improvement (Põder, 2006; Moraes *et al*., 2010; Joachimiak-Lechman, 2013). Hence, a study that provides clarifications on how to assess environmental aspects, during the planning phase, may play an important role on the implementation of an EMS.

According to ISO14001, an environmental aspect is an element of an organization's activities, products and services that can interact with the environment (IPQ, 2015). In fact, the standard provides a guide with some general environmental aspects: emissions to air, releases to water, waste disposal (particularly hazardous waste), use and contamination of land, use of natural resources and raw materials, local issues (noise, odour, dust, use of space, etc), transport issues, risk of environmental accidents, risk of impacts arising and effects on biodiversity (Gangolells *et al*., 2009; IPQ, 2015). There are a few studies that already provide some useful methodologies for assessing the significance of an organization's environmental aspects, mostly based on risk assessment and/or multi-criterion assessment. As referred by ISO 14001, an organization should consider environmental criteria such as scale, severity and duration of the impact and type, size and frequency of the aspect. Additionally, it also should consider other criteria, including, applicable legal requirements and the concerns of internal and external interested parties, such as those related to organization values, public image, etc. (Zobel and Burman, 2004; Põder, 2006; Lewandowska *et al*., 2013b; IPQ, 2015).

All ISO standards are reviewed and revised regularly for the purpose of remaining relevant and valuable to the organizations that seek for an environmental certification. Recently, ISO 14001 was revised providing a new version – ISO 14001:2015 (ISO, 2015). This new version has some improvements, comparatively to the previous one (ISO 14001:2004), namely providing an holistic perspective, by focusing on the relevance of both external and internal elements' influence on environmental impact. More specifically, the new version has added new requirements, mainly based on: considering the risk and opportunities associated to the environmental aspects; the constant awareness for the environmental performance improvement (evaluated by performance indicators); the consideration of both internal and external issues affected by the organization; the provision of more detailed studies regarding stakeholders' interests and expectations; the adoption of a preventive behaviour on the environmental policy; the replacement of the concept of 'legal requirements and others requirements' for 'compliance obligation'; the adoption of more detailed action plans to accomplish the organization's environmental goals and, finally, the inclusion of the life cycle thinking perspective upon the identification of the organization's significant environmental aspects. All the above mentioned modifications have had a strong influence on the traditional methodologies applied on the organization for the assessment of environmental aspects, mostly based on multi-criterion assessment (IPQ, 2015; ISO, 2015; Apcer, 2016).

Life Cycle Assessment (LCA), internationally standardized by ISO 14040 and ISO 14044, is a scientific evaluation tool of the potential environmental impacts associated to a product or service through all the stages of its life cycle. Indeed, follows a "cradle to grave" approach – as it goes from raw material extraction ("cradle"), through manufacturing, transport and distribution processes, to the final product disposal after being used ("grave") (IPQ, 2008; IPQ, 2010). These stages are visible in Figure 2.

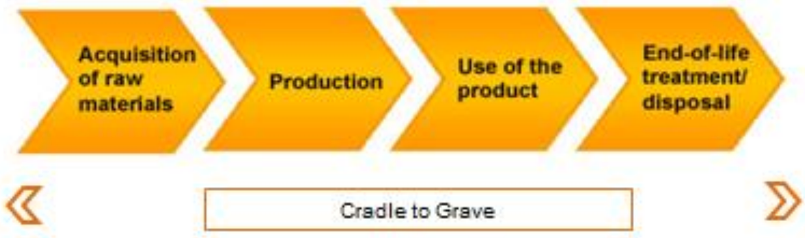


Figure 2. Representation of the different stages addressed by an LCA assessment, on a "cradle to grave" approach. Source: EC-JRC (2012) and Continental Global Site (2016).

This approach has started being used, by the industrial sector, in a small scale, in the late 1960s, having an increasingly growth among the years, mostly as a consequence of the cooperation along the supply chain, as well as of stakeholders and consumers' demands. Currently, LCA may be useful on a diverse set of applications, such as development and improvement of products, strategic planning - by assessing and comparing distinct alternatives (regarding, for instance, raw materials or technologies), eco-labelling systems, ecodesign, integrated product policy, environmental performance assessment and monitoring, environmental communications (either to business customers, as to consumers and authorities), creation of social policy, identification of significant environmental aspects of the organizations' products and services, among others (IPQ, 2008; JRC-IES, 2010c; EC-JRC, 2012; Joachimiak-Lechman, 2013; Lewandowska *et al*., 2013a).

This tool rules himself through 5 principles: the integrated concern of a wide range of environmental problems (such as climate change, human and ecosystem toxicity, resource depletion, among others); it fosters objectivity, throughout the use of scientific and quantitative assessments; allows working with any defined system, from particular type of goods, to companies and even to countries; also, it depicts the whole life cycle of the analysed system – from extraction of natural resources up to waste disposal and, finally, it favours the comparison, on an equal basis, of distinct systems, by using a common unit among the various functions provided by the analysed system – the functional unit. The latter assesses the quantitative description of the system's functions, by naming and quantifying their associated aspects (Finkbeiner *et al.*, 2006; JRC-IES, 2010c; EC-JRC, 2012; Lewandowska *et al*., 2013b).

Thus, the present tool comprises four main phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation phase (Figure 3). A LCA study is iterative, entailing constant revisions of the previous steps throughout the development of the study (IPQ, 2008; IPQ, 2010).

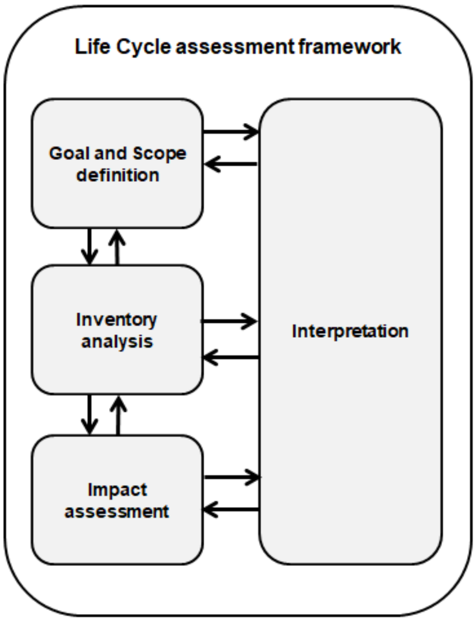


Figure 3. Representation of the different phases of an LCA assessment. Source: IPQ (2008).

Goal definition should, foremost, clearly define the reasons for conducting the study, as well as the intended application(s) and foreseen to be the target audience of the results reached out (IPQ, 2008; IPQ, 2010). Scope definition should, likewise, define the system/process under study, together with the provided functions and provided final product, the selected functional unit and the system boundaries. Also, it should address limitations associated to the method, describing possible assumptions and set data requirements. Moreover, it should set the impact categories to be covered and LCIA methods to be applied. Economic and social aspects and impacts are leaved outside the scope, since LCA has an environmental focus (IPQ, 2008; IPQ, 2010). The inventory phase regards to data collection and inventory flows' preparation, concerning the identified inputs and outputs, meeting the considerations outlined during the previous phases (goal and scope). Life cycle impact assessment (LCIA) includes the transition from inventory data (inputs and outputs of elementary flows), into potential environmental impacts by evaluating their magnitude and significance, concerning the pre-set impact categories and areas of protection (IPQ, 2008; JRC-IES, 2010c; IPQ, 2010; EC-JRC, 2012; UNEP, 2015; PRé Consultants, 2016a). Phasing out the brief description of the representative phases of a life cycle, there is the interpretation phase, which consists on the analysis throughout the life cycle, checking and steering the work performed, as well as on drawing conclusions regarding the results accomplished on LCI and LCIA phases, identifying any significant environmental issues and highlighting limitations and future recommendations (IPQ, 2008; IPQ, 2010; JRC-IES, 2010c; EC-JRC, 2012; UNEP, 2015).

Using LCA for assessing environmental aspects in EMS has some clear advantages in comparison to traditional approaches: it provides a standardised methodology; enables the inclusion of quantitative information as well as obtaining quantitative results; presence of well-documented and more complete data (on account of assessing both the direct and indirect environmental aspects, by considering other stages of the life cycle); includes methodological steps which enhance a simpler verification of the collected data; is characterised by the availability of a broad possibilities of software supporting the assessment and has the ability to obtain reproducible, reliable and scientifically relevant results (Zobel *et al*., 2002; Lewandowska, 2011; Lewandowska *et al*., 2011; Joachimiak-Lechman, 2013; Lewandowska *et al*., 2013b). It also can be observed a certain number of limitations such as: the complexity of the procedure; time consumption and higher costs (especially related to inventory phase, particularly on the first assessment); the impossibility to assess qualitative aspects, such as those related to emergency situations; lack of relevant data concerning environmental aspects on the currently used LCIA methods and a risk that the methods may not capture all environmental impacts (Lewandowska, 2011; Lewandowska *et al*., 2011; Joachimiak-Lechman, 2013; Lewandowska *et al*., 2013b).

Despite the pointed limitations, the use of LCA on the assessment of environmental aspects is still a suitable option. Hence, it ought to be used not as a replacement of the traditional approaches but in addition to them, since it promotes transparency, comprehensiveness and scientific approaches (Finkbeiner *et al.*, 2006; Lewandowska, 2011; Lewandowska *et al*., 2011). In fact, the Integrated Product Policy communication (IPP), in 2003, has stated that LCA provides the best framework for assessing the potential environmental impacts of products, currently available (EC-JRC, 2012).

Undoubtedly, the implementation of an EMS and, consequently, the environmental certification has been significantly looked for, having a distinguished growth of certified organizations in the last years. Despite being a voluntary standard, its adoption brings many virtues for those who govern themselves by it, such as: improvement of environmental and management performance (also encourage suppliers' environmental performance by integrating them in the organization system); promotes prevention actions rather than corrective ones; provides a competitive advantage; improvement in legal compliance and regulatory requirements; improvement of relations with authorities, stakeholders and the surrounding communities, promoting the organization's reputation by showing a greater transparency and credibility; increases leadership and employees involvement and provides economic advantages by incorporating environmental issues into business management, achieving an higher exploitation of the *'win-win'* potential of ecological and economic benefits. The overall advantage/requirement of the EMS certification is the continuous improvement of the corporation in all their procedures (ISO 14004, 2004; Zobel, 2008; Testa *et al*., 2011; ISO, 2015; PRé Consultants, 2016; Tourais and Videira, 2016).

The International Organization for Standardization performs, on an annual basis, a survey, evaluating the number/percentage of joining organizations, per standard, per continent, per country, per industrial sector and per year. In 2015, the worldwide results showed 319,324 numbers of certifications by ISO 14001, of which 318,377 still with the old version and 947 already with the updated version (from 2015 revision), presenting an increase of 8% (more 22,588 certifications) comparing to the previous year. Particularly in Europe, the results also showed a small raise on the certifications from 2014 (119,072) to 2015 (119,754). In Portugal, however, seems that 2014 have had a higher number of certifications than in 2015, decreasing from 1321 to 1272 certifications (ISO, 2017a, 2017b).

In this context, for the purpose of having an EMS efficiently implemented, the corporation must have a suitable methodology for assessing the environmental aspects that significantly influence the environment, since they form the basis for setting environmental objectives, targets and management programmes of any organization.

1.2. Objective

The overall objective of this study is to address different methodologies for assessing environmental aspects in an EMS and to propose the most adequate methodology, according to the available data of a chosen case study organization, by taking in consideration the specifications of the new version of ISO14001:2015. According to that standard, it will be required to weight all the environmental aspects related to the under study organization's activities, services and products, in order to measure their significance by using a proposed quantitative methodology, based on LCA. The organization selected for the case study is Continental Mabor – a tire manufacturing industry. Hence, the proposed methodology own to be compared with the currently applied on the organization under study, which represents a qualitative/semi-quantitative methodology, based on multi-criterion.

1.3. Thesis structure

The present thesis is organized in a way that allows the readers to understand the current importance of having a successfully EMS adopted in every organization. Additionally, and inherent to the EMS implementation success it reveals the need for implementing an efficient methodology capable of assessing the organizations' environmental aspects, enabling to set environmental goals and targets and, hence, achieving continuous improvement over time.

For that purpose, firstly, an in-depth literature review was performed to i) understand the relevance of an EMS certification to an organization ii) discover which are the requirements for a successful EMS implementation iii) discover which methodologies have been used for assessing the significance of environmental aspects iv) understand how LCA can be used as a methodology for this purpose and v) understand the environmental implications and specifications of a tire life cycle and, thus, the concerns of a tire manufacturing industry.

Secondly, a series of flowcharts describing all the methodologies, redrawn from literature, were elaborated to assess environmental aspects, providing an easier overview of what has already been studied and proved to be (in)efficient when applied in different organizations - some entail evaluation through multi-criterion, some through risk analysis and others, to less extent, through LCA.

Thirdly, data from the case study organization was collected and presented: the production unit process was selected, according to the most suitable option, and their environmental aspects were studied, gathering all the information necessary to a later application of the selected methodology.

Fourthly, a spreadsheet was developed to enhance the calculation of the environmental impacts concerning the specifications of the chosen methodology, enabling an easier identification of the significant environmental aspects.

Lastly, a critical analysis of the results was executed in order to stress the most suitable methodology, according to the available data.

This study is structured and divided in seven main chapters, as follows below:

- First chapter – Introduction – consists on performing the theoretical context of the problematic under study, explaining the importance and relevance of the present thesis on the current days and presenting what have already been performed concerning the subject. Additionally, this initial chapter presents the objectives and the thesis structure;

- Second chapter – Case study Organization: Continental Mabor – consists on performing the organization presentation, mainly the history of its foundation, the values and principles upon which they rule themselves with and the procedure's current state;
- Third chapter – Description of methods selected for evaluation – presents a description, step-by-step, of the methods selected to be under study;
- Fourth chapter – Proposed methodology – contains, by considering the different methods under study, a proposal of a methodology that has demonstrated to be more adequate to be applied to the under study organization's data. Also, it exhibits the goal, scope and the inventory analysis performed along the study;
- Fifth chapter – Results – exhibits the results reached out through the application of both the proposed methodology and the current methodology already applied on the tire plant;
- Sixth chapter – Discussion – depicts the present study results' in comparison with the whole framework of studies regarding to the area under study;
- Seventh chapter – Final Considerations – shows, ultimately, in a clear way, the conclusions drawn from the present study.

1.4. Literature review

The potential environmental impact of an organization is reflected on the efficiency of its environmental management and performance, so it is crucial to recognize the activities, products and services that may significantly influence the environment, by identifying and quantifying their environmental aspects. Among the identification of the organizations' environmental aspects, it should, firstly, be performed a differentiation between the conditions upon which the aspects are identified, that is, their status situation. For that purpose, there might be considered normal operation conditions (the aspect is associated to the normal machine/procedure operation), abnormal conditions (where are considered situations that are not planned for the everyday operation and can be associated to breaks in the machines/procedures for reasons such as maintenance, machine's malfunctions, and others) and, even, emergency situations (aspects rising from incidents, evaluated by their risk degree) (Apcer, 2016). The organization can only work on those aspects which can control (direct aspects) and those upon which can only have some influence (indirect aspects) (Gernuks *et al.,* 2007; Ljubas and Sabol, 2011; Petrosillo *et al*., 2012; IPQ, 2015).

EMS is designed, in compliance with ISO14001 or EMAS, for being implemented in diverse organizations (different types of activities, size, technology advancement, market position and different ecological motivations) which entails the need for a high level of flexibility in the required specifications by the certification (Lewandowska, 2011). In this context, ISO14004 states that there is no single approach for identifying environmental aspects and environmental impacts, and determining significance that will suit all organizations (ISO 14004, 2004; Lewandowska, 2011). Therefore, it is the responsibility of the organization to select the most suitable methodology for assessing the significance of their environmental aspects (Gernuks *et al.,* 2007).

According to ISO14001, a significant environmental aspect is an environmental aspect that has or can have a significant environmental impact (IPQ, 2015). An organization doesn't have the ability to prevent and mitigate every environmental aspects at once, so there must be a method used for their prioritization, allowing to decide which ones will became subject of control measures and which ones will became subject of improvement measures (USBR, 2012).

For the purpose of assessing efficiently the organization's environmental aspects, it is necessary to select a transparent and stringent methodology, making it possible to achieve credible and reproducible results, and so, meeting the demands of interested parties. The efficiency of the methodology can also be measured by the inherent level of subjectivity and the common need for personal interpretation of the process, being most of the times, very dependent on the person/team work responsible for applying the method (Zobel *et al*., 2002; Gernuks *et al.,* 2007; Marazza *et al*., 2010; Hauschild *et al.*, 2013). It is possible for a methodology to gather these characteristics if a detailed description of data, information and work procedures are made, in a way that other employees would be capable of going through the procedures and obtaining the same data. Thereby, it is essential to have a structured and detailed documentation (Zobel *et al*., 2002). Alongside, it is also very important, in order to enhance methodology efficiency, to choose methods with low complexity procedures and low consumption time and associated costs, as well as acceptance towards scientific community (basing the assessment rather on scientific models than in personal preferences), geographical representativeness (consideration of local environmental sensitivities), completeness and reliability of data and, finally, understandability for decision-makers, increasing the company acceptance of the method

(Gernuks *et al.,* 2007; IPQ, 2010; Lewandowska, 2011; Hauschild *et al.*, 2013; PRé Consultants, 2016).

In literature many difficulties in assessing environmental aspects have been registered in the past years, such as: difficulty in defining environmental aspect; lack of scientific knowledge over environmental cause and effect relationship, necessary for comparison between different environmental impacts; brief description of the impacts; undefined assessment criteria; high variability of methodologies for assessing environmental aspects, due to absence of an universal measure suitable for different environmental impacts; inherent level of subjectivity associated to the procedure and the information not being described or documented in a structured way. All this constrains lead to inconsistencies in the procedure, which promote lack of transparency, stringency and credibility in the assessment results (Zobel *et al*., 2002; Zobel and Burman, 2004; Zackrisson, 2005; Põder, 2006).

Studies have been underlining different credible and reproducible methodologies for assessing environmental aspects, either through risk assessment, as from using multi-criterion evaluations and also, by using LCA methods (Joachimiak-Lechman, 2013). In fact, according to Lewandowska *et al.* (2013), organizations have been adopting much more qualitative and semi-quantitative techniques for assessing environmental aspects (Lewandowska *et al*., 2013a). Hence, a discrepancy between the different methods studied in literature was found, where there are much more methods using multi-criterion than using LCA.

Risk assessment has been mostly used as complement to other assessment types, mainly in the evaluation on emergency situations, by analysing the probability of the aspects' occurrence and possible damage/effect (Impel, 2012; Joachimiak-Lechman, 2013). Some examples include the study performed by Moraes *et al*. (2010), who used risk assessment together with LCA and the study of Põder (2006), who combine risk assessment with a multi-criterion assessment.

Studies on the use of multi-criterion to assess environmental aspects have been presented by diverse authors, differing from each other mainly on the criteria selection, which may regard to environmental and/or business concerns. According to Zobel et al. (2002) and Zobel and Burman (2004) the main criteria underlined in the literature are: level of environmental impact (using variables such as scale, severity, magnitude, permanence, damage, etc.), level of control upon the aspect and associated existing improving measures, regulatory/legal compliance, concerns of stakeholders (including public complaints), surrounding sensitivity factors (sensitivity areas, ecologic net effects, etc.), economical and technical concerns and the frequency of occurrence. There may be appointed several authors who already work with the stated criteria, proving their efficiency, such as Põder (2006), Edalat (2008), Marazza et al. (2010), Gangolells et al. (2011), Ljubas and Sabol (2011), Testa *et al.* (2011), Gajdzik and Wycislik (2012), Jan et al. (2012), USBR (2012), SCCM (2014), among others. Furthermore, Testa *et al.* (2011) has additionally presented a study wherein consider a multi-criterion methodology, specific for assessing indirect environmental aspects.

There are various methodologies that can be used for performing a LCIA, each one with specific particularities (for instance, consideration of distinct impact categories or distinct characterisation factors). The methodology should be selected according to its suitability to address the impacts of the system under study, as well as its capacity to fulfil the aforementioned criteria of methods' efficiency. Hence, some of the methodologies that have been used on EMS during the last years are CML 2001/2002 (Guinée *et al.*, 2001), Eco-indicator 99 (Goedkoop and Spriensma, 2001), Ecopoint method – or also named ecological scarcity method (FOEN, 2009), IMPACT 2002+ (Jolliet *et al*., 2003), TRACI (Bare, 2011), EDIP (Danish Ministry of the Environment, 2005), ReCiPe (Goedkoop *et al.*, 2013), ILCD (JRC-IES, 2010a, Hauschild *et al.*, 2013), among others (EC, 2011; Klinglmair *et al*., 2014; UNEP, 2015; PRé Consultants, 2016; GreenDelta GmbH, 2017). Likewise, in order to reach reliable resource and emissions inventory data when applying LCA, there are some known scientifically accepted databases for use as a complement to site-specific data. Some examples of databases include: Ecoinvent, ProBas, GaBi, NEEDS, Franklin USA 98, Ökobau.dat and ELCD (European Life Cycle Database). Moreover, there is SimaPro software which entails several databases for user's selection, according to their own needs (Frischknecht *et al*., 2007; Ecoinvent, 2017a; Lewandowska *et al*., 2013b; PRé Consultants, 2016a; ELCD, 2017; myEcoCost – Sustainable Production Support Tools, 2017; openLCA, 2017; Franklin Associates Ltd 98, 2013).

LCIA allows reaching the significance of the environmental impact of each substances collected during the inventory phase – inputs and outputs – by quantifying their potential environmental impacts (JRC-IES, 2010c; IPQ, 2010). This stage is divided in six steps, three mandatory (selection of impact categories, category indicators and characterization models; classification and characterization) and three optional (Normalization; grouping and weighting) (IPQ, 2008).

Firstly, impact categories, category indicators and characterization models to have under evaluation should be selected. Next, inventory flows are classified according to the pre-set impact categories and indicators, concerning their ability to contribute to different environmental problems. Examples of those environmental problems include, on midpoint level (impact pathway), climate change, acidification, eutrophication, ozone depletion, photochemical oxidant formation, particulate matter formation/respiratory inorganics, radiation, land use/occupation, resource depletion and toxicity (human, terrestrial, freshwater and marine). Likewise, on endpoint level (damage impact – evaluation of affected set areas of protection (AoP)) are considered human health, ecosystem diversity and resources availability. These categories may suffer some variations depending on the method chosen to be applied – in this case, the mentioned categories regard to the ReCiPe method (JRC-IES, 2010a, 2010b, 2010c; IPQ, 2010; IPQ, 2008).

Then, the under study substances will be assigned with characterisation factors, which is the quantitative representation of the potential impact of each substance, in a common unit. For example, all the substances contributing to climate change are coupled with kg of carbon dioxide (CO_2) equivalents' unit. Methane (CH_4) is scored with 34kgCO_2eq, while CO_2 is only scored with 1kgCO_2eq, which reflects the higher climate change potential of CH_4. The calculation of characterisation factors is performed per advanced modelling, concerning fate analysis, exposure, effects and damages analysis. (JRC-IES, 2010a, 2010b, 2010c; IPQ, 2010; IPQ, 2008).

These first three steps, as stated, are mandatory during a LCIA and determine the contribution of each aspect to the overall impact. Thus, Figure 4 presents, on a schematic way, a possibility of a complete cause-effect chain - from inventory data, passing through midpoint level where assesses the impact pathway, until the ultimately damage effect, on endpoint level (JRC-IES, 2010a, 2010b, 2010c; IPQ, 2010; IPQ, 2008).

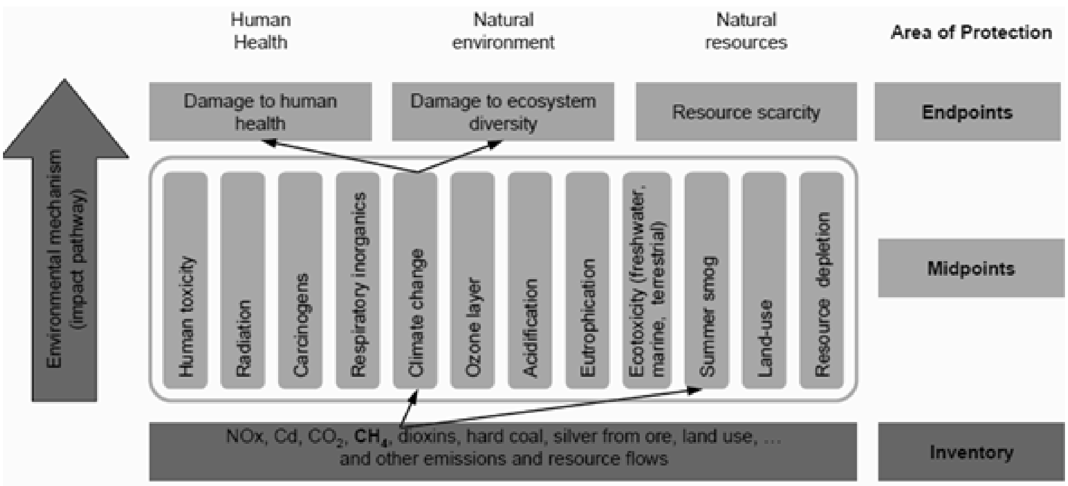


Figure 4. Representation of a possibility of a complete cause-effect chain, from inventory data until the ultimately damage effect. Source: JRC-IES (2010c).

After reaching LCIA results (throughout mandatory steps), the three optional steps might be used to favour their interpretation. Thus, normalisation factors express the magnitude of results, for each category indicator, towards a reference data (i.e. resources/emissions from a reference region, on a reference year). Moreover, grouping allows categorizing results, fostering an easier overview. Lastly, weighting factors conveys the different relative importance between impact categories and/or areas of protection, by ranking their environmental impacts throughout the use of judgement values. (JRC-IES, 2010a, 2010b, 2010c; IPQ, 2010; IPQ, 2008).

As the recommendation for using a life cycle thinking perspective, while assessing the significance of environmental aspects within an EMS context is recent, having appeared only in ISO 14001:2015, literature on this subject is scarce. In fact, only a few studies are available on this topic, such as: Zobel *et al.* (2002), Jolliet *et al.* (2003), Gernuks *et al*. (2007), Moraes *et al*. (2010), Lewandowska (2011) and Lewandowska *et al*. (2011).

With the purpose of joining together the benefits of the three different methods for assessing the significance of the environmental aspects, Liu *et al*. (2012) proposed a new method combining LCA, risk assessment and multi-criterion evaluation.

Assessing the significance of organizations' environmental aspects and setting environmental objectives and targets is not a one-time action. In order to accomplish improvement it is necessary to update this data. It is advisable to do so during the management review, performed once a year. By this means, environmental aspects, objectives and targets are evaluated and, according to new projects/changes in the organization as well as changes in the legislation, new ones are establish regarding to the possibility of new significant environmental aspects being found (Zobel, 2008; SCCM, 2014; Apcer, 2016).

With the recent version of ISO 14001 – ISO 14001:2015 - emerged the need for studies capable of providing efficient methodologies, based on LCA, for assessing the significant environmental aspects, so that companies could update their certification to the new required standards.

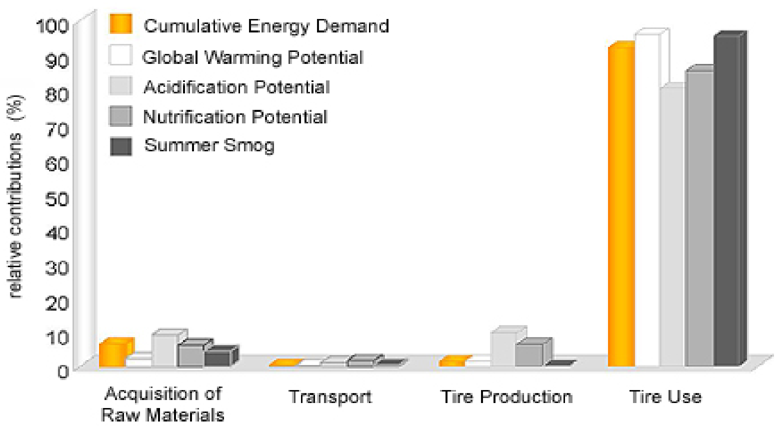
1.5. LCA studies applied to tires

The present study will take place in Continental Mabor, a tire manufacturing industry, where data about their activities, services and products will be collected and where a new proposed method will be applied in the assessment of the identified environmental aspects of the organization. Then, a critical analysis of the results will be performed, in order to stress the efficiency of the suggested methodology, in opposition of the already applied on the organization under study.

Since this study will be applied on a tire manufacturing industry it has to take in consideration the specifications and details that exist around the entire tire manufacturing process, starting on the resources required for production, going through the actual manufacturing of the tire and respective use phase and ending on the existing end-of-life tires effective management systems, thereby respecting the life cycle perspective foreseen to be considered during this work.

Constant increasing in urbanisation has fostered an increase on transportation demand and, hence, on tire production. In Europe, tires are manufactured in about 90 plants and had already reached high levels of production (355 million per year) being responsible for 24% of the worldwide production (Torretta *et al*., 2015).

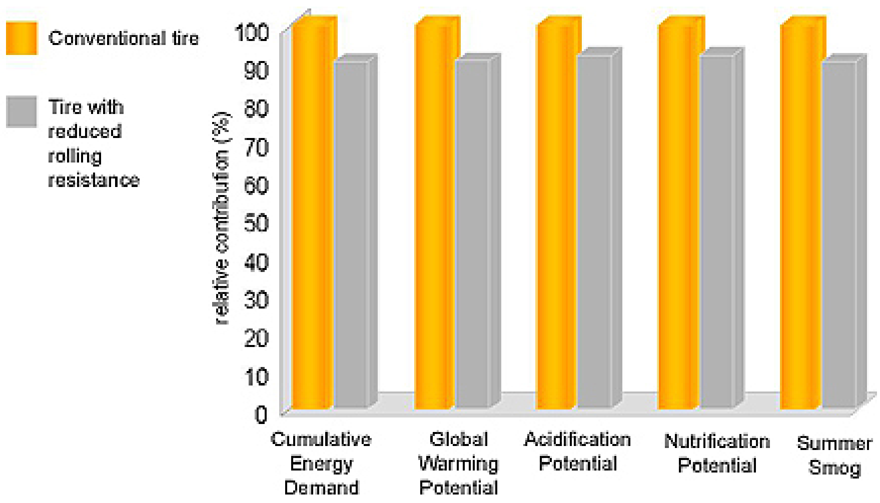
Continental AG, the headquarters of Continental Mabor, has performed a LCA study that estimates the environmental impacts caused during the different stages of the life cycle, stating that the most negative stage is the use of the tire (Graphic 1). Thus, revealing the importance of having an holistic perspective when assessing the environmental aspects associated to the production of a tire, clearly not represented by the production phase. Therefore, a methodology for assessing environmental aspects that does not take into consideration all the phases of a tire´s life, does not represent its real environmental impact (Continental AG, 1999; Continental Global Site, 2016).



Graphic 1. Representation of the environmental impacts associated to the different stages of the tire life cycle. Source: Continental Global Site (2016).

Thereby, it is of great importance to minimize the environmental impacts caused by the actual use of the tire, which can be accomplish by altering the composing tire's material, used in their production. The most important characteristics to have under study, as mostly responsible for the environmental impacts of this stage, are the tires' rolling resistance, weight, pressure, noise and tires' wear/life expectancy. Except for the noise emission, every other mentioned characteristic are correlated with fuel consumption and CO_2 emissions and, hence contributing to climate change. Each tire accounts for about 5.2% of a car's fuel consumption, so in total, the four tires are responsible for 21% of that consumption. Moreover, tires' wear promotes soil and water contamination, potential impacts on fauna and flora, as well as implies the use of new resources (Continental AG, 1999; Ferrão *et al*., 2008; Continental Global Site, 2016).

The reduction of the tire's rolling resistance fosters a decrease of the environmental impact inherent to the tire's use phase (as represented on Graphic 2). However, it might lead to unsafe situations, since it raises the braking distance. Thereby, it is necessary to find a balanced rolling resistance between safety and environment. Continental, in the last years, has been succeeded in lowering the rolling resistance of their tires in about one-third, while improving safety-critical features (Continental Global Site, 2016).



Graphic 2. Representation of the difference between a conventional tire and a tire with reduced rolling resistance. Source: Continental Global Site (2016).

When a tire no longer has the characteristics to fulfil its original purpose – secure and efficient driving – it becomes waste, or so called "end-of-life tire" (ELT). ELT are non-degradable waste that when have no management system associated and are simply landfilled may have considerable serious health and environmental impacts (Torretta *et* *al*., 2015; Malijonyte *et al.*, 2016). Firstly, discarded tires present slow rates of natural degradation, being very resistant to microorganisms, due to the cross-linked structure of rubber and also to the presence of stabilizers and other additives used in their production, hence, resulting on an immense amount of land occupation, as well as resulting on visual pollution for the surroundings. Furthermore, tire landfilling promotes insects' proliferation, by providing sites for mosquito larva development, which can be very nocuous for human health, once they are vectors of diseases. Also, used tires are of ease combustion, being always associated with a dangerous uncontrolled risk of fire, as it is extremely difficult of being extinguish, and it may lead to water and soil contamination. It can also induce eco-toxicity, caused by the leaching of metals and other tire's constitutional materials (as stabilizers, colorants, plasticizers, etc.), air pollution and the release of a black smoke and toxic gas emissions. Additionally, by landfilling used tires, they are being prevented from being used as a resource entering useful end-use markets (Ferrão *et al*., 2008; Torretta *et al*., 2015). Owing to the several listed negative health and environmental impacts associated to this practice, European Union (EU) has already banned the disposal of ELTs in landfills throughout the Directive 1993/31/EC (Adamcová *et al*., 2014).

Because landfilling is no longer an alternative, and the end-of-life planning is an important step in the development of a sustainable product, new managements systems had to be developed, in order to give a proper end to the used tire, with the lowest possible associated environmental impacts. The two main utilities that can be exploited are material recovery as new resources to other uses as a first priority and, if not possible, energy recovery, serving as a replacement for non-renewable fossil fuel (WBCSD, 2010; Torretta *et al*., 2015). Tires are excellent resources, to be used either as material as for energy recovery, due to their inherent characteristics, such as: high resistance to bacterial degradation, mildew, heat, sunlight and general chemicals and their much appreciated elastic properties. Moreover, they have a high calorific potential (due to their high carbon content) (Torretta *et al*., 2015; Malijonyte *et al.*, 2016).

Within the material recovery market, depending on the tire condition, it can be retrieved, extending its life cycle for a longer period of time, or simply used for their material properties. The former is possible when the tire tread depth has reached the limit set by EU law but the rest of the structure still fulfil the standards specifications for a safe driving. So, the tread is regenerated and the tire is sent back to the use market. In the latter, the recovery process is based on the material recycling, enabling their use as new resources. There are already several possible applications to this kind of material studied and proved to be efficient, such as: applications in civil engineer (shredded, cut or used as a whole – for instance on noise barriers), or as ground rubber (used as rubber modified asphalt, recreational surfaces, athletic track applications, among others) (WBCSD, 2010; Torretta *et al*., 2015).

The energy recovery market is divided into three via of generation of tire-derived fuel (TDP): incineration in utility, cement work and pyrolysis. All bring many virtues when applied, mainly preventing excessive raw material consumption by providing an alternative to the electricity and non-renewable fossil fuel use, as well as reducing greenhouse gases emissions released by industrial production and minimizing waste production (Ferrão *et al*., 2008; WBCSD, 2010; Torretta *et al*., 2015).

The raising perception of environmental issues by the society leads to an increase on legal policies spurring the industrial waste prevention. Thereby, in 2001, Portugal has adopted the decree-law 111/2001, which determined the creation of an ELT management system, being thus, one of the first countries to adopt this approach. The non-profit society responsible for the management system of wasted tires in Portugal is Valorpneu, working alongside with Portuguese Environmental Agency (APA), Industrial Rubber Association (APIB), the Portuguese Retreaders Association (ANIRP), Biosafe and Recipneu (Portuguese recyclers) and ACAP (Automobile Commercial Portuguese Association). As a non-profit society, Valorpneu endorses the extended producer responsibility (EPR), which is based on the polluter-pays principle (PPP). Therefore, producers, distributers and importers are obliged to pay a fee for each ELT sent to Valorpneu, which in turn has to pay compensations to collectors, distributors, recyclers and incinerators (Ferrão *et al*., 2008).

The already performed LCA study from Continental (regarding a car tire) (Continental AG, 1999), presented the material/energy flows and every resource requirement, as well as has quantified and evaluated every emissions and waste generated throughout the various stages of the tire's life cycle, thus identifying the main environmental impacts inherent to the tire's life. Also, it has performed a comparative study of different end-of-life management systems, based on the associated environmental impacts. The main consumed resources referred to in this study were silica, rubber, carbon black, steel, petroleum and water. Likewise, the main emissions registered were carbon dioxide, carbon monoxide (CO), water vapour (H_2O), methane, nitrogen oxide (NO), volatile organic compounds (VOCs), sulphur dioxide (SO_2), ammonia (NH_3), nitrous oxide (N_2O) and dust, when considering air emissions. Considering water emissions, the emissions considered were chloride ions (Cl^-), sulphate ions (SO_2^-) and sodium ions (Na^+). Thereby, the main categories of impact identified were: global warming effect, acidification, nitrification, ecotoxic and human-toxic potential, despising the noise emissions associated to the tire. The three different end-of-life (EOL) management systems under study addressed in this report were the full retreading of the tire (substitution of the worn tread for a new one, extending the tire's life cycle), cement production (overridden hard coal for worn tires, reducing the environmental impacts associated to the process, such as global warming potential, acidification and nitrification) and energy recovery in power stations.

As the present study is mainly based on a life cycle perspective it is necessary to gather detailed information about the existing research on tire's life cycle stages and their implications in the environment, making it possible to perform a conscious work on the case study industry, regarding to their data – namely, their production process and respectively environmental aspects, as well as the environmental aspects associated to the remaining stages of their product's (tire) life cycle.

2. Case study organization: Continental Mabor

2.1. History

Continental was founded on October 8, 1871 in Hanover, Northern Germany, as a joint stock company, manufacturing soft rubber products, rubberized fabrics and solid tires for carriages and bicycles. Since then, has evolved steadily and, today, it is among the top 5 worldwide automotive suppliers. The corporation is divided into the Automotive group and the Rubber group, consisting of five divisions of production: chassis & safety, powertrain, interior, tires and contitech. With an evident continuous growth, the company has been spreading around the world, having already locations in Europe, Africa, Asia, Australia, North America and South America, in a total of 49 countries. This study took place in Portugal, where Continental is represented by Continental Mabor – Indústria de pneus, S.A. This organization was founded in 1989, having emerged from the union between Continental AG and Mabor – Manufatura Nacional de Borracha, S.A., the first tire plant in Portugal. On those days, Continental Mabor had a production capacity of only 5000 tires per day. Since then, this plant has been growing and expanding and, nowadays, the daily production is of about 50,000 tires, which makes this plant one of the Continental fabrics with the highest productivity levels. This organization has a total surface of 303,584 m^2, of which 144,450.6 m^2 are covered and work with about 1794 employees (Continental Global Site, 2016; Continental Mabor, 2017).

2.2. Values

Despite its vast production, Continental Mabor has concerns regarding the safety of work conditions and the environment, ruling themselves through ESH (Environment, Safety and Health) policy. This policy has a couple of principles that have to be strictly followed, mainly: compliance with applicable laws and internal guidelines; development of processes and products that promote sustainable environmental protection (mostly in climate-change mitigation); reducing, as possible, consumption of natural resources; conducting operational emergency management and taking preventive measures concerning all employees, by providing training, information and motivation so they can work safely and with concern to the environment. Additionally, the industry promotes the inclusion of contracted partners, suppliers and customers in its ESH-activities, as well as the communication and monitoring of ESH performance.

The present organization has been seeking for a continuous improvement in their procedures since their environmental certification, in 1996, by ISO 14001 standard.

Today, they have already updated the last revisions and upgrades of the standard, so being in compliance with the new requirements of the ISO 14001:2015 (Continental Global Site, 2016; Continental Mabor, 2017).

In this context, Continental Mabor presents a strong commitment towards environmental protection inasmuch as it conducts a series of practices towards the promotion of environment quality. This sort of characteristics makes this organization ideal for the realization of the present study.

2.3. Tire production process

Tire production is, undoubtedly, a broad process, encompassing seven different phases (represented on Figure 5). Primarily, and in order to supply the needs for the actual manufacturing procedures, the organization receives and store the necessary raw material to the entire process. The actual production phase starts with the mixing process, going through preparation phase, tire building, curing process and finally, when the tire accomplishes its final configuration, the final finishing phase where the tire meets its future destination. Indeed after finishing tire's inspection, if it is according to the pre-set requirements it is stored and distributed to its intended clients. The following chapters present the specifications of each one of the production phases aforementioned:

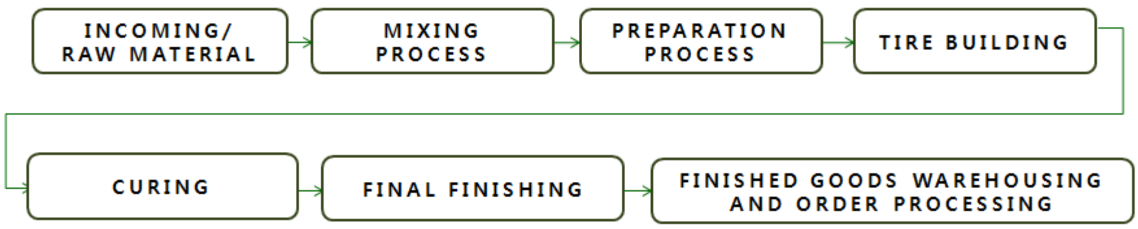


Figure 5. Flowchart representing the tire production process.

2.3.1. Incoming raw material

To enable using the raw material necessary to the tire's manufacturing, there are some requirements that have to be fulfilled. Thereby, from the choice of the supplier to the actual use of the compounds, there are some specifications and decisions that have to be performed in order to successfully receive and store the material until needed. Primarily, in order to supply raw material used in any Continental tire plant it is required to be certified by ISO 9001 and recommended to be certified by ISO/TS 16949. Adding to these specifications, on an annual basis, all the suppliers are subject to a performance evaluation, considering their quality performance, as much as their price policy. Once the supplier is chosen, the next concern is about their supplies transportation. There is transport specific regulation for each kind of material that has to be fulfilled, such as the transportation companies' environmental certification, allowing to control their air emissions. Also, the loading area must be clean and non-contaminated (free of dust, rust, oils, etc.), free of any material that may damage the supplies (such as protruding nails or screws), covered from sunlight, dust, water, among others harmful aspects and must be in perfect conditions to prevent infiltrations. Upon the arrival of the material and the associated unloading in the proper area, it is performed a process of weighting and inspection, so that the material could be approved and, hence, stored in the raw material warehouse.

In order to produce properly any type of tire, there is a group of pre-set raw materials foreseen to be needed, as it is stated in the following list, which presents all the raw material necessary to the production process, as well as each material's contribution to each tire formulation:

- Rubber (natural or synthetic) – 38%;
- Fillers (carbon black, silica, …) – 30%;
- Reinforcement materials (steel, polyester, nylon, rayon) – 16%;
- Plasticizers (oil, resins) – 10%;
- Curing agents (SO_2, ZnO, accelarators) – 4%;
- Ageing protective agents (antidegradants, waxes, resins) – 1%;
- Other materials (Binding agents, additives, …) – 1%.

2.3.2. Mixing

The very first step of tire production is the mixing of a pre-set group of compounds. Currently, the industry has a total of 11 active mixing machines, divided in 3 groups: those who mix only final compounds (mixer 0, 1 and 3), those who mix only master compounds (mixer 2, 4, 5, 6, and 7) and those who mix both together in the same mixing machine – OSM / One Step Mixing (mixer 9, 10 and 11). To every mixing procedure it is essential the presence of carbon black, silica and process oils.

The main difference between the final compound and the master compound is the presence, on the first one, of curing agents (essentially, sulfur). So, the master compounds are processed by using non-cured rubber – natural and synthetic - and small chemicals. When finished they will, firstly, go through the strainer machine (strainer 1), in order to remove the presence of defects and imperfections, and then, be used as rubber on the mixing machines 0, 1 and 3 to form the final compound, before entering the next phase.

Likewise, the final compounds processed on the 0, 1 and 3 mixing machines also have to go through the strainer (strainer 2), which has a few specifications, such as process temperature, due to the presence of curing agents, in order to prevent the rubber's curing during this process stage. From here they are transported and stored in the automatic compound storage (ACS), for further pick-up into the preparation phase, when ordered.

Before entering the mixing machines there are several process stages that need to be taken into account, mainly: the incoming, storage, weighting (manually or automatically) and supplying of the machines with the necessary raw material. Also, either on the mixers, as in the strainers, the rubber goes through an area of batch-off in which they are washed with an anti-tack solute, favouring their further stacking, thus making their transportation easier.

These compounds are produced according to the further sub-products they are intended for. Different tire's components requires different types of rubber, therefore, they are named with a code regarding to their specifications, so that they can be transported to the correct zone and used properly in the various stages/machines of preparation phase.

2.3.3. Preparation

Preparation phase is where the sub-products that will constitute and form the tire are processed, using the final compound mixed and formulated in the previous phase, together with reinforcement raw material – wire, steel cord and textile/hybrid cord. For that purpose, those sub-products, foreseen to be used as tire's components, are manufactured in two different stages, mainly differentiated by their work temperature. In the hot preparation stage, the following elements are processed: tire bead and extrusion of the tire side wall and of the tire tread. Likewise, the cold preparation stage is represented by the calendering and cutting of sub-products according to the pre-set specifications of the tires they are intended for. Thereby, it is considered the calendering of the innerliner, calendering of gum sheet and steel cord, forming the breaker, calendering of textile fabrics and cap-strip extrusion. These sub-products will then be transported to the building area, so that together may form the future tire.

2.3.4. Tire building

The sub-products manufactured in the previous phase are here assembled in order to produce the green tire. Firstly, there is the construction of the tire carcass, consisting of the montage of the tire bead together with the innerliner, the tire sidewall and textile fabrics. To the tire carcass are added the tire tread, breakers and a cap-ply layer, giving place to the green tire, which in turn will be transported to the curing area.

2.3.5. Curing

In the curing area, the green tire will go through several changes in its configuration. Initially, it starts by being sprayed, in order to favour the further adhesion to the diaphragm. Then, it is transported into the curing machines, where it will be cured, on steam presses, and molded, by compression, into the diaphragm. This procedure is associated with high temperatures and pressures, which causes deep modifications on the tire's material properties. Thus, guaranteeing characteristics such as resistance, stability and durability. In this phase, the tire will accomplish its final configuration. From this area, it is transported to the ultimately phase, the final finishing phase, in order to ascertain the quality parameters of the finished tire.

2.3.6. Final finishing

To finish the tire production process it is necessary to confirm the fulfilment of the quality parameters established either by legal requirements or by the future clients. Therefore, the tire has to go through visual inspection, where non-conformities are looked for (for instance, bubbles, components' imperfections, inadequate painting, etc.). If non-conformities are not found on the initial visual inspection, then the tire is sent directly to the machines where they are subject to a uniformity test as well as a geometry test (bulge detector). If the operators detect abnormalities on the tire, they send it to the retouching and the tip-top area, so that these imperfections may be repaired. If so, they join the conformed tires' in the next phase – the uniformity and geometry test. If the non-conformity is not able to be repaired, the tire is considered scrap and it is sent to the waste area, for further ELT management.

Passing the uniformity test, the tire can either be sent directly to finish goods storage to further pick up and distribution or it can still has to go through a balancing test, depending on the client it is intended for. If the tire is considered non-conforming, is sent to a repairing area, in which the tire will go through bead expansion and scraping machines. It passes again through the uniformity test and if is still non-conforming is considered scrap and sent to the waste area, for further ELT management. If the parameters are fulfilled, the tire will join the conformed tires' in the next phase – balancing test or finished good storage.

Regarding the tires sent to balancing test, the parameters are checked and if they are fulfilled, the tires are approved and sent to the finish goods storage to further pick up and distribution. If the parameters present non-conformities the tire is marked as scrap and sent to the waste area, for further ELT management.

2.3.7. Water treatment for consumption and wastewater treatment

These two phases, per se, are not part of the production process. However, they are mandatorily associated to it, as they are responsible for the water's provision to the entire organization, as well as responsible for the wastewater treatment. Thus, they play an important role among the production process, minimizing, to a great extent, their environmental impacts.

Water resource is used in several steps of the production process, namely in the cooling towers, for steam generation and for proper use of some machines/procedures. For these purposes, the resource is withdrawn from Ave River, which passes nearby, throughout wells and holes constructions. Hence, the water is captured, analysed and treated, according to pre-set specifications, regarding to the purpose which will be intended for. Firstly, it is received on a reception tank, wherein will be added with hypochlorite and sodium hydroxide. Then, it will go through a series of treatment procedures, in order to reach the intended parameters, such as: coagulation/flocculation, decantation, filtration through sand filters and activated carbon filters and decalcification.

During the production process, there are several points which generate wastewater that cannot be sent back to the river, due to the pollutant load that presents. So, these wastewaters are treated with the purpose of being recovered and used again, as new resource - mainly, on cooling towers and cleaning areas. At the wastewater treatment plant, the wastewater is, firstly, received on a reception tank, wherein the industrial effluents are homogenized in order to promote water characteristics uniformity and to avoid any solid's deposition on the tank. Next, it goes through a physical and chemical treatment, based on a coagulation/flocculation process, as well as a decantation procedure, wherein the sludge is separated from the water. The former is forwarded to the sludge tank, where the sludge is pressed, dehydrated and sent to the waste area as dangerous waste for further elimination. The latter is forwarded to the treated water tank, throughout a sand filter, and, then, to the processes where it is needed. When it is not possible to reach again the set parameters for a new use of the same resource, the water is sent to SIDVA (Integrated System for Ave River Decontamination) that will perform the necessary treatment procedures to return the water to the river.

2.4. Environmental aspects identification

Inherent to the fact that the tire manufacturing process is very extensive, it would be unfeasible to assess the environmental aspects of all the activities, products and services of the whole organization, in such a short period of time. Thereby, the present study will only work with data associated to the mixing phase, always in a life cycle thinking perspective, as Figure 6 depicts.

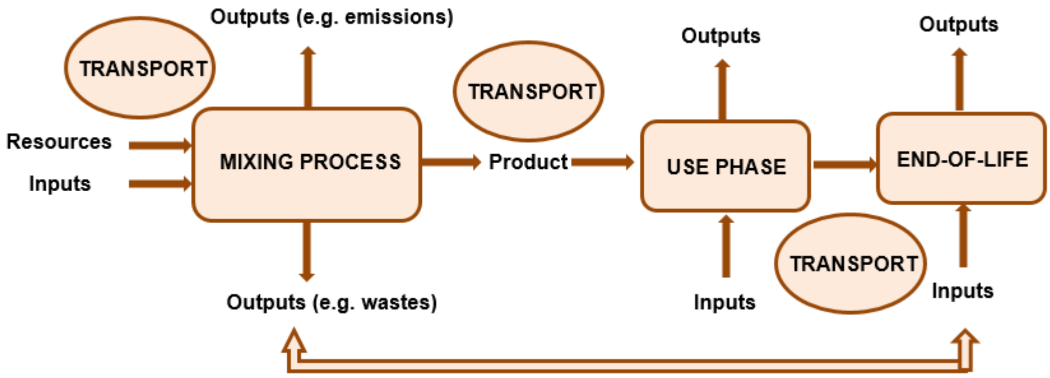


Figure 6. Representative flowchart of the different stages associated to environmental aspects identification on a life cycle thinking perspective. Source: adapted from JRC-IES (2010c).

The organization has categorized the environmental aspects into distinct environmental categories, enabling a better understanding of their respective environmental impact and an easier prioritization by significance. Thereby, the types of environmental aspects already considered are:

- Contributing to the raising levels of pollution - air emissions, wastewater, generation of waste and soil contamination;
- Contributing to the decline of worldwide resources - water, energy, fossil fuels and raw material consumption;
- Nuisance.

The following sub-chapters present the whole framework of environmental aspects associated with the mixing phase, the unit process selected to represent the production stage (sub-chapter 2.4.1), as well as the indirect environmental aspects associated with this phase, already on the concern of the company (sub-chapter 2.4.2.). The information addressed below was redrawn from reports furnished by the organization under study.

2.4.1. Mixing phase environmental aspects

The present chapter identifies the direct environmental aspects associated with the mixing process, which are those under control of the organization, as opposed to the indirect environmental aspects, represented by stages such as “resources extraction” (indirect impact upon the resources consumed in the mixing phase), “transportation stage” (indirect impact either during the resources consumption, as well as during waste generation), “use stage” and “tire’s end-of-life management” (indirect impact upon the whole waste generated, including the worn product).

Figure 7 represents the connections between inputs and outputs concerning the particular case of the mixing process, also addressing the water consumption and treatment after being used. The latter are performed by the organization itself, being also considered as direct environmental aspects.

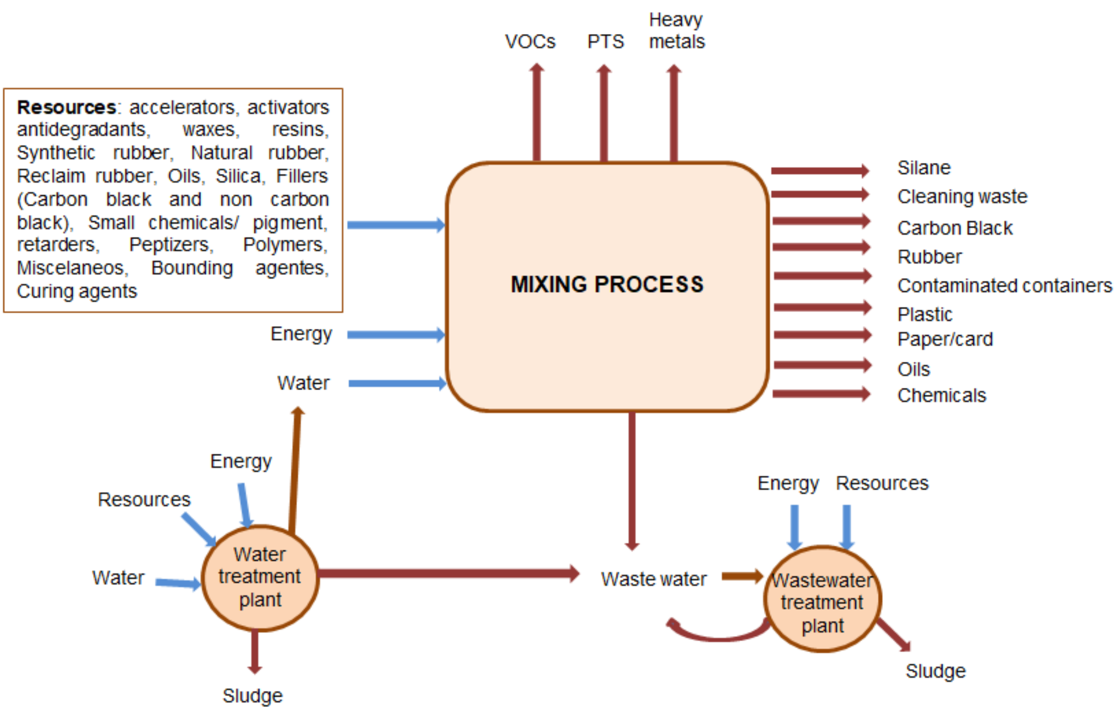


Figure 7. Mixing process and associated environmental aspects identification. The blue arrow represents the inputs in the system and the red arrow represents the outputs.

The aspects' identification was performed by the organization itself, using an FMEA/FMECA method – Failure Mode and Effect Analysis – by identifying potential failures which may result in environmental accidents, characterizing the associated cause and environmental effect/damage.

In order to enhance an environmental aspects' identification data more structured and amenable, the organization has divided the mixing phase into 10 distinct stages of procedures, plus the water and wastewater treatment plant (not strictly part of the production process but associated to it). These stated stages are addressed below, regarding to their environmental aspects and are represented, on a sequential flowchart, in Figure 8.

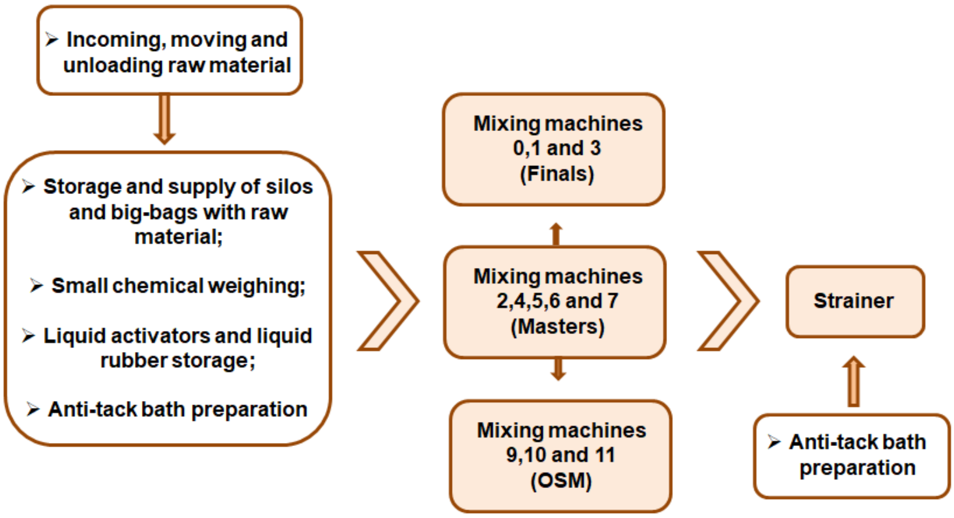


Figure 8. Flowchart representing the stages of the mixing process.

Incoming, moving and unloading raw material

In this initial stage of the mixing process, the identification of environmental aspects is divided in five steps: transportation to the organization, internal transportation, incoming of oils, carbon black and silica and raw material unloading.

Transportation to the organization is associated with the transportation company hired and it presents four environmental aspects: air emissions, nuisance, fossil fuels consumption and, possibly, in emergency situations, soil contamination.

Internal transportation presents three environmental aspects: air emissions, fossil fuels consumption and, possibly, in emergency conditions, soil contamination.

Among the raw material incoming on the organization, particularly, during the oils reception, it is recorded the generation of dangerous waste, either in normal as in emergency situations and wastewater generation in normal work conditions. Relatively to the incoming of carbon black and silica are record air emissions, mainly total suspended particles (TSP), either in normal work conditions as in emergency situations. Moreover, there might possibly be generated non-dangerous and non-reusable waste, carbon black, as well as dangerous waste classified as 'chemicals waste' (mainly associated to silica), on emergency situations.

During unloading operation, there are several environmental aspects identified, namely: air emissions (TSP release); dangerous waste generation (classified as cleaning waste, accounting mainly with contaminated cleaning cloths, gloves, proper suits or even paper/cardboards or plastics used during cleaning process and which have been contaminated) and non-dangerous, reusable waste (carbon black); energy consumption and nuisance. All were registered amongst normal work conditions. Concerning abnormal situations, there might be identified air emissions (TSP) and dangerous and non-dangerous waste generation (cleaning waste and carbon black, respectively).

Throughout the course of the present analysed stage there is a constant risk of fire associated that requires most caution, since it may have dangerous consequences. It is known that the fire is connected to the release of air emissions, waste water and waste generation.

Figure 9 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing the occurrence of environmental accidents.

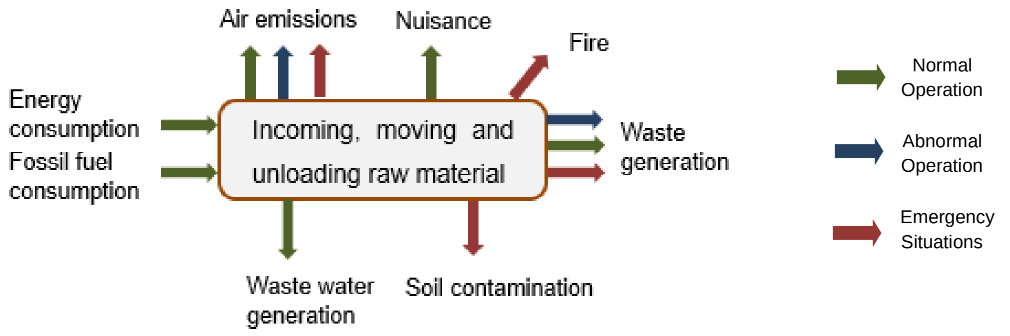


Figure 9. Representation of incoming, moving and unloading raw material's stage environmental aspects.

Storage and supply of silos and big-bags with raw material

After receiving the raw material it is necessary to proceed with its storage, until needed in the production area. For that purpose, carbon black, silica, process oils and zinc oxide are stored in monthly silos, on a first stage, passing through daily silos and/or bigbags.

When storing oils in monthly silos, in abnormal operations, during its maintenance, dangerous waste might be generated (cleaning waste). Dangerous waste may also be generated among emergency situations, mainly due to oil spills. In case of carbon black storage, different environmental aspects are considered. Normally, it is associated with energy consumption and nuisance and, in abnormal operation, with non-dangerous waste generation (carbon black) and air emissions release (TSP). Likewise, there are also differences when storage is made upon daily silos, in which air emissions (TSP) and dangerous waste generation (cleaning waste) may occur, when in abnormal operation. In order to supply these machines (daily silos), air emissions (TSP) are, normally, released and, in abnormal operations, dangerous waste (cleaning waste) is generated.

Associated to the transportation system, responsible for the transition from the monthly to the daily silos, there are identified environmental aspects such as nuisance and energy consumption, in normal conditions, and air emissions (TSP) and dangerous waste generation (cleaning waste) in abnormal operation.

Finally, also considered in this stage is the supply of unloading bigbags facilities, which is normally associated with air emissions (TSP). Moreover, in abnormal operation, it might generate non-dangerous and reusable waste (carbon black), dangerous waste (cleaning waste, chemicals and contaminated containers) and release air emissions (TSP). Besides, on possible emergency situations, air emissions (TSP), dangerous waste (chemicals) and non-dangerous, reusable waste (carbon black) may also arise.

Figure 10 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing the occurrence of environmental accidents.

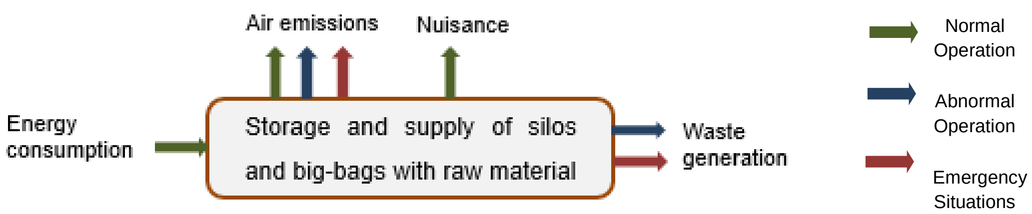


Figure 10. Representation of Storage and supply of silos and big-bags with raw material's stage environmental aspects.

Small chemical's weighting

Small chemical's weighting process can be performed on a manual or automatic way, by the use of proper machines. In order to identify the environmental aspects in a clear way, the chemical's weighting stage is differentiated in 6 steps: small chemicals supply into production buffer, production buffer storage, bigbags substitution, bins filling (manual weighting), small chemicals' manual weigh and small chemicals' automatic weigh.

The small chemicals supply into the production buffer is associated with non-dangerous and reusable waste generation, regarding to plastic and paper/cardboard and with energy consumption, in normal operation. Furthermore, in possible emergency situations, dangerous waste may be generated, mainly through the generation of chemicals and contaminated containers.

The production buffer storage is known by generating, in normal work conditions, both non-dangerous, reusable waste (such as plastic and paper/cardboard) and dangerous waste (like chemicals and contaminated containers).

The step regarding bigbags substitution is associated with air emissions (including TSP and heavy metals) as well as with dangerous waste generation (including chemicals and contaminated containers). Moreover, in possible emergency situations, air emissions (TSP as heavy metals) may be released.

During bins' filling process, typical from manual weighting, there are records of air emissions release (TSP and heavy metals) and dangerous waste generation (contaminated containers). Still regarding this step, in possible emergency situations, dangerous waste (such as chemicals and contaminated containers) may also be generated.

In the actual weighting process, there were differences found among the identification of environmental aspects when concerning manual work in opposition to automatic work, performed by machines. Thus, in the former are identified, in normal work conditions, air emissions (same as the above stages) and energy consumption. Furthermore, in emergency situations, is identified the possibility of dangerous waste generation, mainly including chemicals and contaminated containers. In the latter, in normal work conditions, air emissions (same as the above stages) and energy consumption are identified. On the other hand, in abnormal operation, are identified air emissions (same as the above stages) and dangerous waste generation, concerning cleaning waste. Finally, amongst emergency situations, dangerous waste (such as chemicals and contaminated containers) as well as air emissions (TSP and heavy metals) may arise.

Figure 11 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

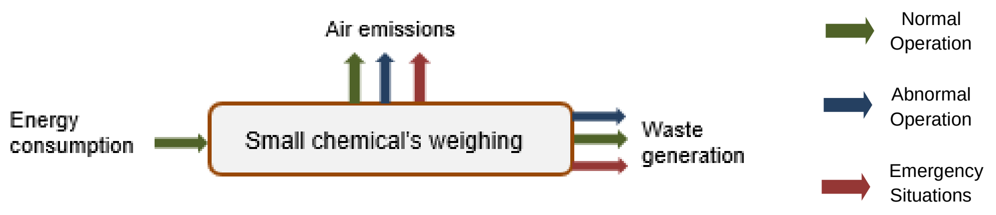


Figure 11. Representation of Small chemical's weighting stage environmental aspects.

Mixing machines 0, 1, and 3 (finals)

The final compound's mixing stage is parted in six steps, in order to identify the environmental aspects on a structural base: raw material transportation to the mixing machine, process of unloading the compounds into the machine as well as the actual mixing process, mills homogenization, batch off, scrap collection and, finally, the rubber transportation to the preparation area or to the ACS.

Concerning the raw material transportation to the mixing machine step (rubber, carbon black, silica, small chemicals and zinc oxide) there are considered, during normal operation, energy consumption and non-dangerous, reusable waste generation, such as plastics and paper/cardboard waste. Also, in possible emergency situations, it may be generated dangerous waste, mainly through chemicals generation.

Among the process of unloading the compounds into the machine and the actual mixing process there are identified, in normal operation, the following environmental aspects: energy and raw material consumption; air emissions (mainly through Volatile Organic Compounds (VOCs) and TSP release); nuisance; dangerous waste (due to oils generation amongst mezzanines greasing - specific mixing machine's structure) and non-dangerous, reusable waste (due to plastics and paper/cardboard generation). Conversely, in abnormal situations, there are considered and evaluated air emissions (VOCs and TSP release), dangerous waste (due to cleaning waste generation) and wastewater generation. Finally, it might also be considered, in possible emergency situations, dangerous waste generation (chemicals).

During mills homogenization step there are recorded, during normal operation, four types of environmental aspects: energy consumption, air emissions (mainly by VOCs release), non-dangerous, reusable waste (rubber generation) and nuisance.

During the batch-off step, which includes bath, transportation, drying and palletizing, there are identified, concerning normal operation, environmental aspects such as energy consumption, non-dangerous and reusable waste (rubber waste generation), nuisance and air emissions (VOCs release). Conversely, on abnormal situations, are identified wastewater and dangerous waste generation (cleaning waste), upon the machine's maintenance. Moreover, in emergency situations, it is considered the hypothesis of wastewater generation, as well as dangerous waste generation (mainly due to anti-tack bath waste spills and, hence, cleaning waste generation).

Finally, when the final compound is finished, it is transported to the ACS and to the preparation area, which requires energy consumption and, in emergency situations, may generate dangerous waste - classified as cleaning waste.

Alongside with this stage there are records of scrap collection, mainly of rubber waste, and a high risk of fire associated that, when it occurs, may release air emissions and generate dangerous waste and wastewater.

Figure 12 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

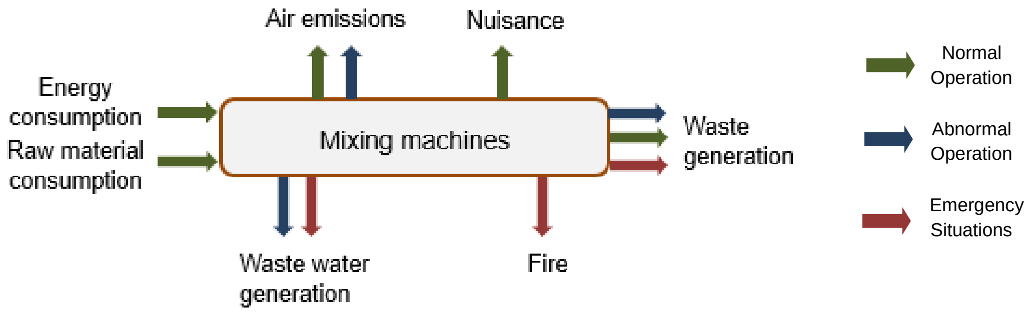


Figure 12. Representation of mixing machine's stage environmental aspects – concerning 0, 1 and 3 machines.

Mixing machines 2, 4, 5, 6 and 7 (masters)

The master compounds mixing stage is divided in the same six steps than the final compound flow, with only one difference – the master compound doesn't go to the preparation area, it is only allowed to do so after being transformed into final compound. Thereby, in order to identify the environmental aspects, on a structural base, the following steps are considered: raw material transportation to the mixing machine, process of unloading the compounds into the machine, as well as the actual mixing process, mills homogenization, batch off, scrap collection and, finally, the rubber storage in the ACS.

Concerning the raw material transportation to the mixing machine step (rubber, carbon black, silica, small chemicals and zinc oxide) there are considered, during normal operation, energy consumption and non-dangerous, reusable waste generation, such as plastics and paper/cardboard waste. Also, in possible emergency situations, it may be generated dangerous waste, mainly through chemicals generation.

Among the process of unloading the compounds into the machine and the actual mixing process there are identified, in normal operation, the following environmental aspects: energy and raw material consumption; air emissions (mainly through VOCs and TSP release); nuisance; dangerous waste (due to oils generation amongst mezzanines greasing - specific mixing machine’s structure) and non-dangerous, reusable waste (due to plastics and paper/cardboard generation). Conversely, in abnormal situations, there are considered and evaluated dangerous waste (due to cleaning waste generation) and wastewater generation. Finally, it may also be considered, in possible emergency situations, dangerous waste generation (chemicals), as well as air emissions release (concerning VOCs and TSP).

Carbon black compound, used during this stage, is totally recovered, being used again as resource in the following mixtures. Regrettably, in spite of resource saving, this recovery procedure requires energy, in normal operation. Also, upon the structure’s maintenance, on abnormal operation, dangerous waste is generated (cleaning waste). Likewise, during normal operation, the procedure of supplying the recovered carbon black into the mixing machines also requires energy consumption, as well as releases air emissions (TSP). Regarding to possible emergency situations, in both cases (recovery and supplying) it is considered the possibility of air emissions release, mainly concerning TSP. This recovery process is only possible with master compounds due to the absence of curing agents.

During mills homogenization step there are recorded, during normal operation, four types of environmental aspects: energy consumption, air emissions (mainly by VOCs release), non-dangerous, reusable waste (rubber generation) and nuisance.

During the batch-off step, which includes bath, transportation, drying and palletizing, there are identified, concerning normal operation, environmental aspects such as energy consumption, non-dangerous and reusable waste (rubber waste generation), nuisance and air emissions (VOCs release). Conversely, on abnormal situations, are identified wastewater and dangerous waste generation (cleaning waste), upon the machine’s maintenance. Moreover, in emergency situations, it is considered the hypothesis of wastewater generation, as well as dangerous waste generation (mainly due to anti-tack bath waste spills and, hence, cleaning waste generation).

Finally, when the final compound is finished, it is stored in the ACS, requiring, for that matter, energy consumption.

Alongside with this stage there are records of scrap collection, mainly of rubber waste, and a high risk of fire associated that, when it occurs, may release air emissions and generate dangerous waste and wastewater.

Figure 13 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

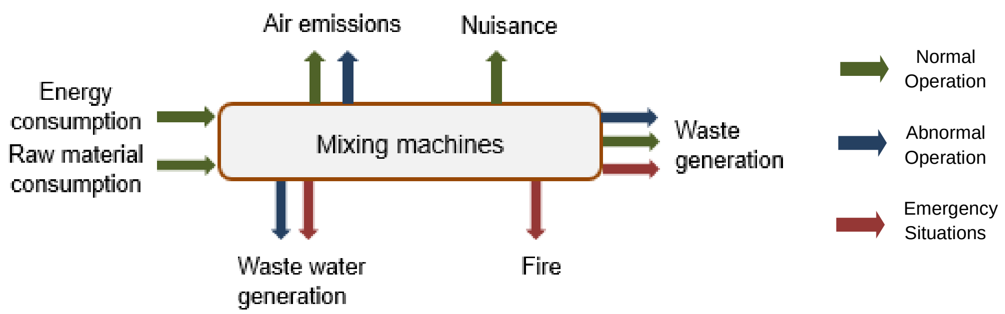


Figure 13. Representation of mixing machine's stage environmental aspects – concerning 2, 4, 5, 6 and 7 machines.

Mixing machines 9, 10 and 11 (OSM)

The OSM (One Step Mixing) compounds mixing stage is divided in the same six stages than the final compound flow, with the particular difference of mixing together master and final compounds. Thereby, in order to identify the environmental aspects, on a structural base, the following steps are considered: raw material transportation to the mixing machine, process of unloading the compounds into the machine, as well as the actual mixing process, calender extruder step, batch off, scrap collection and, finally, the rubber transportation to the preparation area or to the ACS.

Concerning the raw material transportation to the mixing machine step (rubber, carbon black, silica, small chemicals and zinc oxide) there are considered, during normal operation, energy consumption and non-dangerous, reusable waste generation, such as plastics and paper/cardboard waste. Also, in possible emergency situations, it may be generated dangerous waste, mainly through chemicals generation.

Among the process of unloading the compounds into the machine and the actual mixing process there are identified, in normal operation, the following environmental aspects: energy and raw material consumption; air emissions (mainly through VOCs and TSP release); nuisance; dangerous waste (due to oils generation amongst mezzanines greasing - specific mixing machine's structure) and non-dangerous, reusable waste (due to plastics and paper/cardboard generation). Conversely, in abnormal situations, there are considered and evaluated dangerous waste (due to cleaning waste generation) and wastewater generation. Finally, it may also be considered, in possible emergency situations, dangerous waste generation (chemicals), as well as air emissions release (concerning VOCs and TSP).

During calender's extruder step there are recorded, during normal operation, four types of environmental aspects: energy consumption, air emissions (mainly by VOCs release), non-dangerous, reusable waste (rubber generation) and nuisance.

During the batch-off step, which includes bath, transportation, drying and palletizing, there are identified, concerning normal operation, environmental aspects such as energy consumption, non-dangerous and reusable waste (rubber waste generation), nuisance and air emissions (VOCs release). Conversely, on abnormal situations, are identified wastewater and dangerous waste generation (cleaning waste), upon the machine's maintenance. Moreover, in emergency situations, it is considered the hypothesis of wastewater generation, as well as dangerous waste generation (mainly due to anti-tack bath waste spills and, hence, cleaning waste generation).

Finally, when the final compound is finished, it is transported to the preparation area or to the ACS, requiring energy consumption.

Alongside with this stage there are records of scrap collection, mainly of rubber waste, and a high risk of fire associated that, when it occurs, may release air emissions and generate dangerous waste and wastewater.

Figure 14 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

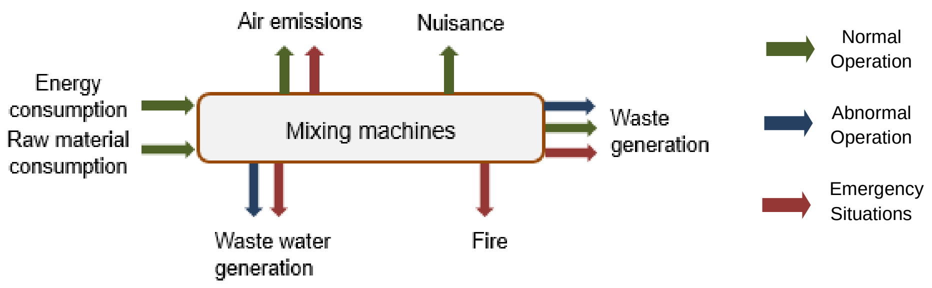


Figure 14. Representation of mixing machine's stage environmental aspects – concerning 9, 10 and 11 machines.

Strainer

Finished the mixing stage, the final compound will be purified on the strainer, namely by granules and air bubble's removal. For the identification of the environmental aspects of this process stage, it is performed a division by steps: mills supply, procedures regarding to feeding mills, calender extruder and finish mills and, ultimately, the batch-off step.

During mill's supply step are identified, on normal operation, energy consumption, air emissions (VOCs release) and non-dangerous and reusable waste generation (rubber waste).

Either in feeding mills as in calender extruders or in finishing mills, there are always associated to the process, on normal operation, environmental aspects such as energy consumption, air emissions release (VOCs), nuisance and non-dangerous, reusable waste generation (rubber). Furthermore, in abnormal operation as well as on emergency situations, there might be identified wastewater generation.

During the batch-off step, which includes bath, transportation, drying and palletizing, there are identified, concerning normal operation, environmental aspects such as energy consumption, non-dangerous and reusable waste (rubber waste generation), nuisance and air emissions (VOCs release). Conversely, on abnormal situations, were identified wastewater and dangerous waste generation (cleaning waste), upon the machine's maintenance. Moreover, in emergency situations, it is considered the hypothesis of wastewater generation, as well as dangerous waste generation (mainly due to anti-tack bath waste spills and, hence, cleaning waste generation).

Alongside with this process stage there is associated a high risk of fire that, when it occurs, may release air emissions and generate dangerous waste and wastewater.

Figure 15 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

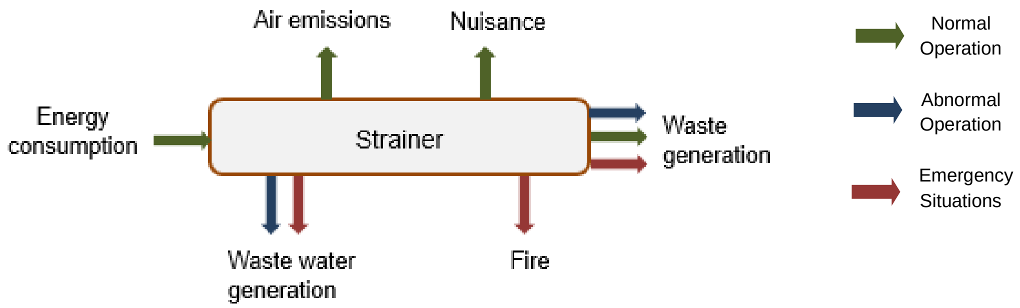


Figure 15. Representation of strainer's stage environmental aspects.

Anti-tack bath preparation

The anti-tack bath preparation is performed to facilitate rubber's compound stacking, in order for this to be easily transported either to the ACS as to the preparation area. This process stage is divided in three distinct steps, in order to favour the environmental aspect's identification: solute transportation to the bath preparation facility, mixing and the mixing tanks supply.

The solute transportation step requires energy consumption and, on possible emergency situations, may generate dangerous waste, through anti-tack bath waste spills and, hence, cleaning waste generation.

During the mixing step, in normal operation, it is required energy, water and raw-material consumption. The latter regards mainly to Alkon consumption – substance which enhance anti-tack. When in abnormal operation, it is generated wastewater and, conversely, when in emergency situations, may be considered dangerous waste generation (possible anti-tack bath waste spills and, hence, cleaning waste generation).

Finally, in order to supply the mixing tanks with this bath's mixture, it is considered, in normal operation, energy consumption and, in abnormal situations the generation of wastewater.

Figure 16 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

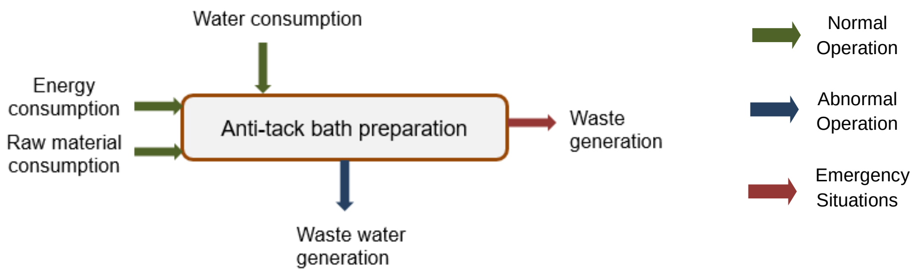


Figure 16. Representation of anti-tack bath preparation's stage environmental aspects.

Liquid activators and liquid rubber storage

Liquid activators and liquid rubber are used as raw material, together with carbon black, small chemicals and process oils, on the mixing machines. This particular compound's storage stage is divided on four distinct steps during the environmental aspect's identification: production buffer storage, heating station's supply, heating station's stage and the supply into the mixing machines.

Among the first step – production buffer storage – is considered energy consumption, associated to normal operation. Moreover, regarding to emergency situations is considered the possibility of being generated dangerous waste (chemicals, silane and cleaning waste generation).

During heating station's supply step is identified non-dangerous and reusable waste generation (plastic and paper/cardboard), in normal operation, and, on emergency situations, is identified the possibility of dangerous waste generation (chemicals, silane and cleaning waste).

Both in the heating station's step as in the raw material's supply into the mixing machines there are identified environmental aspects such as energy consumption, in normal operation, and dangerous waste generation (cleaning waste), in abnormal operation.

Alongside with this process stage there is associated a high risk of fire that, when it occurs, may release air emissions and generate dangerous waste and wastewater.

Figure 17 line-up the whole possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as in abnormal operation (blue arrow) or even as emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

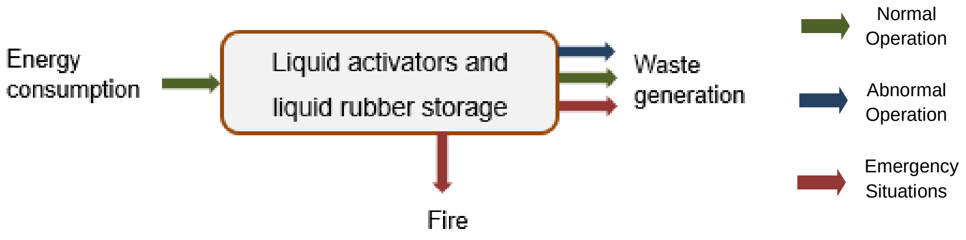


Figure 17. Representation of Liquid activators and liquid rubber storage stage environmental aspects.

Scrap

Relatively to the scrap collection around this particular production process phase, it mainly regards to possible emergency situations which may occur. Hence, it is associated to the generation of cleaning waste (dangerous waste). Furthermore, in normal operation, this stage requires energy consumption.

Figure 18 line-up the possibilities of environmental aspects that may occur during this particular stage of the mixing process, either on normal operation (green arrow), as regarding emergency situation's aspects (red arrow), analysing those aspects who may occur upon environmental accidents.

Figure 18. Representation of scrap collection stage environmental aspects.

Water treatment for consumption and wastewater treatment

The water treatment entails two kinds of treatment: on water for industrial consumption (water treatment plant) and on wastewater, released during the production process (wastewater treatment plant). Both are associated with energy and raw material consumption, as well as with dangerous waste generation, more specifically, sludge generation. Upon abnormal work operation, wastewater might be generated.

Figure 19 line-up the environmental aspects occurring during this particular phase of the production process, either on normal operation (green arrow), as in abnormal operation (blue arrow).

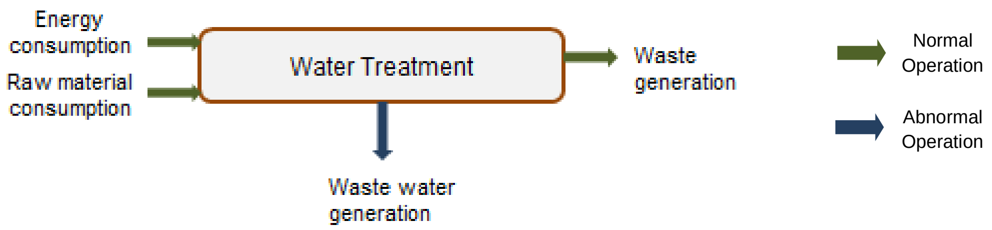


Figure 19. Representation of water treatment phase environmental aspects.

2.4.2. Indirect environmental aspects

The only stage truly controlled by the organization is the production stage, including, as well, water treatment stations – either for consumption as from the wastewater generated by the production process. The concerns about the remaining stages are responsibility of Continental AG, in Germany. Thus, those stages addressed by the present corporation are, as represented in Figure 20: resources, research and development, pick-up and distribution, tire use and end-of-life tire management.

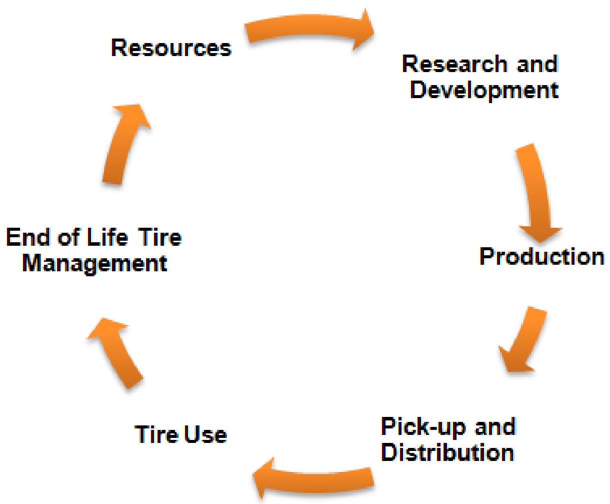


Figure 20. Representation of the different stages of a tire's life cycle.

Continental AG performs an environmental assessment concerning the tire's production indirect stages, by analysing the essential concerns and measures applied to enhance their environmental behaviour. The present chapter reflects, briefly, those concerns and, hence, the corporation's environmental position towards less controllable but still influential stages.

Firstly, among the resources and research and development stages, the organization has in consideration three important sectors: suppliers and transportation's research; raw material purchasing and hazardous substances management. Thus, the stated sectors are addressed below.

Considering the suppliers and transportation's research sector, it is ensured that both of them are in compliance with the corporation's environmental values and expectations. For that purpose, it is necessary to confirm the REACH certification (for chemicals protection) and the presence of MSDS (Material Safety Data Sheets) associated to the substances. Moreover, dangerous substances must be labelled and the quantities, types, properties and containers information must be registered. Also, to guarantee that the suppliers remain improving their performance, they are evaluated on an annual basis. Likewise, transportation issues encompasses questions such as travelled distance, frequency of transportation, type of vehicle used and their safety conditions during the transportation (ensured by their certification), always looking for minimizing, as far as possible, the air pollution and energy consumption inherent to this stage.

Concerning raw material purchasing, it is performed an investigation about the material properties, uses and future possible environmental impacts, in order to make a sustainable and clean option. Therefore, it is relevant to know which are the forbidden (either from legislation, as from customer requirements) and dangerous substances, as well as to promote the use of regenerative and recyclable material. Moreover, is important to be aware of the inherent products of the selected raw material (for instance, carbon black may contain traces of Polycyclic Aromatic Hydrocarbon (PAH)) and to adopt the "sustain" strategy from Material & Process Development & Industrialization (MDPI). The latter consists, basically, on the investigation for innovative material and process technologies, enabling to reach and achieve excellent tire performance at highest stability and productivity.

Regarding to hazardous substances management, a special and closest attention is provided. Thereby, in addition to the formulation and exposure of the MSDS, it is advisable to perform an evaluation of the possible chemical exposure, as well as to register the chemicals with their inherent characteristics and give instructions on how to work with these elements.

Even among the production stage there are some indirect issues non-controllable by the organization. Considering the mixing phase (focus of this study), it is known that, contributing to the feasibility of these production procedures there is a whole "backstage" of studies and surveys performed in order to pursue the most sustainable production flows, reaching the intended compound with the lowest environmental, economic and social impacts. Thus, the main aspects considered and worked by the corporation during the research and development stage, concerning production procedures are: process requirements and specifications for machine operations (shut down temperatures, ram movements, cycle times, etc.); mixing compounds (passes, loading points, temperatures, times, etc.); downstream equipment (responsible for the material processing into the finished product); raw material weighting, storage, transportation and feeding to the machines (cycle times); the correct use of the anti-tack solution at the batch-off facility (concentration, quality, etc.) and raw material pre-treatment equipment and specifications for lay-down temperatures. These intensive research and investigation may lead to the decrease of air emissions (VOCs, dust and odour), waste generation (process oils, etc.), emissions to water and also to the decrease of energy, water and others resources consumption, being of great importance to the overall environmental performance of this process phase.

During tire's manufacturing, there is always a high risk of fire associated to almost every procedure. Thereby, it is necessary to take preventive measures and to have emergency plans, as well as corrective actions well defined in case of occurrence. Fire or explosive incidents may cause air, soil and water contamination, as well as surrounding flora and fauna destruction. It is important to have internal operational fire prevention standards, responsible for establishing extinguishing methods. Those are based on preparing emergency notifications and emergency preparedness, as well as on including the setting of escape routes and rescue assignments. Also, they address the importance of using fluorinated greenhouse gases in extinguishing systems, of retaining contaminated water from fire fighting and on having environmentally relevant requirements of insurance companies. It is equally mentioned the high relevance of always having provisions of water to use for fire fighting. All of these concerns and preventive actions have as main goal the reduction and minimization of air, soil and water pollution, the decrease of waste generation and the raising of human protection.

There is also a research and development stage around the details regarding to the tire, concerning the future implications in their use. Thus, it is important to consider the tire's environmental labelling (providing relevant information to the customers) and the retreadibility of products (sparing the use of new resources, as well as waste generation). Besides those, it is also relevant to address the linkage between the tire's characteristics and the associated environmental aspects arising during the use stage. Therefore, the corporation stress as very important characteristics the tire's rolling resistance, pressure and weight, since they are directly associated to the fossil fuels consumption and indirectly with the vehicle emissions. Also, refers tire's noise as a future cause of disturbance and tire’s wear, associated with generation of dust, potential impacts on soil, surface water, flora and fauna, as well as to foster an increase of the use of new resources.

The optimization of retreading processes, associated with the tire’s life expectancy also includes the end-of-life tire management stage, demonstrating the organization’s environmental producer responsibility, by decreasing waste generation and, hence, promoting the conservation of resources.

Associated to the stated concerns and measures concerning the distinct stages of a tire’s life cycle it is of high relevance the constant creation of environmental awareness, throughout communication and environmental training, both to the employees and to the surrounding community. It is obviously essential to have a real and tangible environmental policy and to perform or undergo through continuous environmental audits – internal and external – in order to continuously improving the organization’s and, hence, the tire’s environmental performance. This kind of conduct will, certainly, decrease the potential environmental impacts and increase stakeholder’s environmental awareness and consciousness, as well as the commitment of the organization towards the legal and customers’ compliance, and also, towards a higher environmental protection. It is also very common inside industrial sector, more precisely, within rubber manufacturers, to exist a collaboration regarding environmental issues, where strategies concerning the environmental protection are defined. Also, stakeholders may be involved by questioning the organization and evaluating their environmental performance.

2.5. Current methodology for assessing Continental Mabor environmental aspects

The studied organization uses two different assessment methodologies: one applicable to the production’s environmental aspects, developed and applied by DSIA (Industrial Safety and Environment Department) and the other, specific for being applied on indirect environmental aspects, created by Continental AG, in Germany.

DSIA’s methodology starts by dividing the production system into unit processes, to favour the identification of the aspects. Then, the aspects are discriminated considering their life cycle stage (resources, research and development, production, pick-up and distribution, tire use and end-of-life tire management), the conditions upon which they were identified (normal, abnormal or emergency) and if they are considered direct (those identified on the production phase) or indirect (those identified on the remaining identified stages of the tire's life cycle). The environmental aspects considered are:

Contributing to raising pollution levels:

- Air emissions
- Wastewater
- Waste generation
- Soil contamination

Contributing to worldwide resource's decline:

- Water consumption
- Fossil fuels consumption
- Energy consumption
- Raw-material consumption

Others:

- Nuisance

After the aspect has been identified, the methodology entails the evaluation of the respective impact, through the use of a multi-criterion type of assessment. Annex 1 presents a schematic table which displays the numerical-scale assigned to the different criteria under study, that is explain below:

- Scale
- Quantification
- Severity
- Probability

Scale criterion is applied according to three levels of scoring: local (1), regional (2) and global damage (3).

Quantification criterion presents differences when applied to different environmental aspects. Concerning air emissions and wastewater, the score is applied in three levels: inferior to legislation set values (1), closed to legislation set values (2) and higher than legislation set values (3). Concerning waste generation and resources consumption (energy, water, fossil fuels and raw material), the score is also applied in three levels, slightly different than those above: inferior to the typical values associated with the procedure (1), closed to the typical values associated with the procedure (2) and higher than the typical values associated with the procedure (3). Concerning soil contamination, it is considered: possible superficial damage (1), possible phreatic surface damage (2) and possible unconfined aquifer damage (3). Lastly, nuisance is assessed through three levels of score: inferior to day-evening-night equivalent level (Lden) and night equivalent level (Ln) legal values (1), closed to Lden and Ln legal values (2) and higher to Lden and Ln legal values (3).

Severity criterion is based on environmental legislation, varying amongst the different considered groups of environmental aspects, reflecting their presence or absence from set control lists. Air emissions are evaluated through two levels of scoring: emission of substances defined in *Portaria* n.º 286/93 of 12th March (DRE, 1993) and in *Portaria* n.º 80/2006 of 23rd January (DRE, 2006) (2) and others emissions, absence from the stated lists (1). Wastewater is evaluated also through two levels of scoring: emission of substances defined in *Decreto-lei* n.º 236/98 of 1st August (DRE, 1998) and by SIDVA (2) and other emissions, absent from the stated list (1). Waste generation is evaluated in three levels of scoring: non-dangerous and reusable waste (1), non-dangerous, non-reusable waste (2) and dangerous waste, according to *Portaria* n.º 209/2004 of 3rd March (DRE, 2004) (3). Soil contamination is measured by the use of two score levels: release of inert products (1) and release of substances defined in *Decreto-lei* n.º 236/98 of 1st August (DRE, 1998) (2). Water consumption is represented by the resource's scarcity level of the area. Thus, it has two levels of scoring: if it is scarce (2) and if is not (1). Among fossil fuels consumption there are represented two score levels: renewable resource (1) and non-renewable resources (2) and, finally, regarding to raw material consumption is evaluated the noxiousness of the material to the environment. Therefore, there are considered two levels of scoring: non-dangerous resources (1) and those who represent noxiousness to the environment (2). Energy consumption and nuisance are aspects not capable of being quantified through this particular criterion, are only assessed with scale, quantification and probability criteria.

Probability is based on the level of occurrence of the aspects which might occur in case of an accident or rarely (1), periodically or occasionally (2) or usually or on a continuously way (3).

Summing up all the results achieved by applying these criteria, the environmental aspect significance goes from value 4 to value 9 or value 12 depending on the aspect under study. Thereby, the significance of the aspect can be despicable (4-6 or 3-5, in the particular case of energy and raw material consumption), moderate (7-8 or 6-7, in particular case of energy consumption and nuisance), and high (9-12 or 8-9, in the particular case of energy consumption and nuisance)

Continental AG methodology regarding to indirect aspect's assessment is completely different, but respecting the same basis of application of multi-criterion to reach the significant indirect environmental aspects. The criteria here applied have two different evaluation objectives – evaluation of environmental impact and evaluation of the control system applied.

Concerning the evaluation of environmental impact, four criteria are considered:

- Frequency
- Impact (intended operation)
- Impact (unintended operation)
- Expectation of external stakeholders

Frequency criterion is measured in three score levels: high frequency, where it is considered occurrence in >20% of working time (4), medium frequency, where it is considered occurrence from >5% to <20% of working time (3) and low frequency, where it is considered < 5% of working time (2).

The impact (intended operation) criterion measures the levels of consumption or potential contribution for reduction of resources, waste generation and air, water and soil pollution. It also evaluates the level of importance for awareness creation and competence, the strategic relevance and the duration of the effects. Thus, it is scored into three levels: high (4), medium (3) and low (2).

The impact (unintended operation) criterion measures the contribution of a failure or deficiencies in the task into the impact of the intended operation. Thereby, it is evaluated into three score levels: high, where it leads to a significant worsening of the impact (4), medium, where it leads to a worsening of the impact (3) and low, where it have a minor or no effect at all on the impact (2).

The expectation of external stakeholders can be measured in three score-levels: high expectation - aspect is part of the customer requirements, is in the focus of political discussion and society's expectation and it had been registered significant complaint's in several plants (4); medium expectation - aspect is in the interest of the customer, it has already begun to be developed political discussion and expectation in the society and had been registered some complaints in a few plants (3) and, finally, low expectation - the aspect is not required by the customer, is not either in the political discussion neither in the focus of society's expectation and there is no register of complaints (2).

Regarding the evaluation of the control system applied, three criteria are considered:

- Organizational measures
- Technical solutions
- Economic benefit

The organizational measures are evaluated in three levels of scoring: they may be considered sufficient, if the responsibilities are well defined, the procedures are in place, there is a regular monitoring system implemented, it has the involvement of a consultant and a study has been conducted (4); medium, if the responsibilities are not clearly defined, procedures are not complete or are unclear and there is an irregular monitoring system implemented (3) and may be considered low, if the responsibilities are not defined, the procedures are not in place, there is no monitoring system implemented, no consultant involvement and no studies or surveys were performed (2).

Technical solutions (machines, equipment, treatment technology, database or IT program) are also evaluated on a three score system. High score (4) is given to when the technical solutions are installed or in implementation phase; medium score (3) is given when the technical solutions are improvable and low score (2) if technical solutions are not in place, are not needed or feasible solutions are not available.

Finally, the economic evaluation refers to the economics associated to the control system of the concerning aspect. So, if there is an economic benefit associated the aspect is scored as high (4); if is neutral (it has no benefit neither needs investment) it is scored as medium (3) and if an economic investment is needed is scored as low (2).

3. Description of methods selected for evaluation

For the selection of the methodologies to apply in the present study, between the many found during the literature review, the most important criterion under consideration was the presence of life-cycle thinking perspective when assessing the organization's environmental aspects, in order to meet the new ISO 14001:2015 requirements and, hence, the demands of the interested parties.

As previously mentioned in sub-chapter 1.4 "Literature review", there are a few applications of LCA on evaluating environmental aspects with regard to their significance in EMS, namely: Gernuks *et al*. (2007), Moraes *et al*. (2010), Lewandowska (2011), Lewandowska *et al*. (2011) and Liu *et al*. (2012). From these, the methodology proposed from Gernuks *et al*. (2007), Lewandowska (2011) and Lewandoska *et al*. (2011) were the ones that appear to be more complete and suitable for the present study. Liu *et al*. (2012), on the other hand, has presented a very complex and impractical procedure which will not be described. Nevertheless, has addressed the possibility of combining LCA with multi-criterion assessment and risk degree analysis that was considered among the proposed methodology development.

Moreover, in order to perform the risk analysis, as a complement to the LCA method, for assessing the environmental aspects rising from emergency situations, Põder (2006), Moraes *et al.* (2010) and Impel (2012) were selected to have in consideration amongst the formulation of the proposed methodology.

That being said, the following sub-chapters describe, in detail, the procedures to apply the methodologies proposed on the most suitable aforementioned papers.

3.1. Lewandowska (2011) and Lewandowska *et al*. (2011)

This methodology proposes the combination of three distinct criteria: environmental, legal compliance and stakeholders' internal/external issues.

Regarding the environmental criteria, is suggested the use of an LCIA method, capable of providing weighting values, among the determination of the contribution of a certain environmental aspect to the overall impact. Then, the impact's percentage of contribution is linked with a numerical scale, as presented in Table 1. This numerical scale is underlined either by Lewandowska (2011) and Lewandowska *et al.* (2011), as well as it is suggested on annex B.2 of ISO 14044:2006 (IPQ, 2010).

Table 1. Numerical scale applied to the impact's percentage of contribution to the overall impact (environmental criteria).

Impact's percentage of contribution to the overall impact	Scoring level
More than 50%	3 points
25%-50%	2 points
10%-25%	1 point
2.5%-10%	1 point
Less than 2.5%	0 points

Regarding to legal regulation's criterion, it is applied a four-point scale evaluation, concerning the existence/compliance with legislation, as presented in Table 2:

Table 2. Numerical scale applied to the legal regulation's criterion.

Legal compliance	Scoring level
Legal regulation exists and it is being broken	3 points
Legal regulation exists and it is at risk of contravention	2 points
Legal regulation exists and it is fulfilled	1 point
No regulation exists	0 point

Regarding to the internal and external issues concerning stakeholders is also presented a numerical scale divided in three score levels, as presented in Table 3:

Table 3. Numerical scale applied to stakeholder's criterion.

Stakeholders	Scoring level
Records of complaints	2 points
General interest	1 points
Lack of interest	0 point

In order to reach a significance value, it is performed the sum of the individual scores per criterion (environmental + legal regulations + stakeholders). When the sum value is equal or above 3 points, the aspect is considered significant. If it is under this value, then the aspect is not considered significant.

The authors stressed that those aspects that are excluded from an LCA study (due to their inability of being clearly defined or due to not having correspondence on the existing databases) but with possibility of still becoming significant environmental aspects, should not be completely excluded from the assessment. In this case, they should be additionally assessed by other existing methodologies, mainly by using multi-criterion.

3.2. Gernuks *et al*. (2007)

Gernuks *et al.* (2007) present a combination of a quantitative and a qualitative assessment, as a way to evaluate the whole organization's environmental aspects, i.e. the quantifiable aspects as well as those with qualitative character. For that purpose, it proposes the use of two distinct methods: Ecopoint method (FOEN, 2009), for quantitative assessment and ABC method for qualitative assessment. Joining both results on a matrix, so as to favour an easier overview to the decision makers.

Ecopoint method is a single-step approach where the environmental burden of each substance, identified during the inventory stage, is determined. This value is reached throughout the application of a pre-set formula, which multiplies the inputs/outputs values for the respective Ecopoints **(a)**. In turn, the Ecopoints are set by applying a different formula **(b)** that uses three different parameters: the current flow (current emission of a substance in a country, per year (F)); the critical flow (maximum emission tolerable, set by legal thresholds or political targets (Fk)) and, a constant variable C (10^{12}/yr), used for easy handling of results.

(a) $$\textbf{Environmental Burden} = \text{Inventory data} \times \text{Ecofactors}$$

(b) $$\textbf{Ecofactor} = \frac{1}{Fk} \times \frac{F}{Fk} \times c$$

These two formulas own to be applied to all the substances, obtaining the environmental burden/individual contribution per substance to the overall impact. Then, the environmental burden values correspondent to each substance contributing to the same environmental aspect are summed up. The result will be compared to the total environmental burden, resulting on the percentage (%) of it contribution to the overall impact in the environment, allowing prioritizing them by environmental significance. The scale used for determine this environmental significance is presented in Table 4.

Table 4. Significance level applied to the impact's percentage of contribution to the overall impact.

Impact's percentage of contribution to the overall impact	Significance level
More than 10%	Very important
1%-10%	Important
Less than 1%	Less important

As it has been stated before, not all relevant environmental aspects are able to be assessed by the Ecopoint method, reason why it has to be performed a complementary qualitative assessment, using ABC method. In this method, Gernuks *et al.* (2007) suggest the use of two distinct criteria for the evaluation: disturbance of the neighbourhood and legal thresholds. Both are classified on a three-level scale, ranging from **A** corresponding to "**very important**" aspects, **B** to "**important**" aspects and ending on **C**, which corresponds to "**less important**" aspects. Regarding to the disturbance of neighbourhood criteria, the significance-scale is applied as presented on table 5.

Table 5. Significance level applied to disturbance of neighbourhood criteria.

Neighbourhood disturbance	Significance level
More than 3 complaints	**A** - Very important
1-3 complaints	**B** - Important
No register of complaints	**C** - Less important

Conversely, regarding legal thresholds criteria, the significance-scale is applied as presented on Table 6.

Table 6. Significance level applied to legal thresholds criteria.

Legal thresholds	Significance level
Aspect is associated with more than 80% of legal threshold	**A** - Very important
Aspect is associated with 50-80% of legal threshold	**B** - Important
Aspect is associated with 0-50% of legal threshold	**C** - Less important

Gernuks *et al.* (2007) have listed the environmental aspects passable of being evaluated through Ecopoint method and those who should be assessed through ABC method. Thereby, in the former are presented the following type of aspects: resources, electric energy, thermal energy, emissions to air, emissions to water, waste and transport issues. In the latter the following are displayed: odour, noise visual appearance, contaminated soils, surface sealing, risks of environmental accidents and environmental performance of suppliers.

Once the environmental aspects significance is determined, both the results from Ecopoint and from ABC method, are transferred to a matrix (Figure 21), favouring an easier overview of the assessment and respective environmental aspects' prioritization.

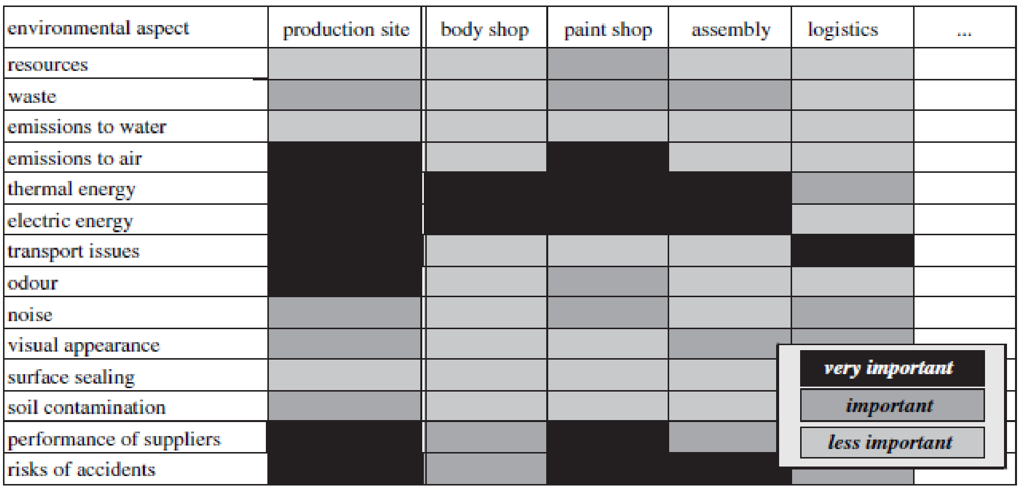


Figure 21. Example of a result's matrix structure. Source: Gernuks *et al.* (2007).

3.3. Põder (2006), Moraes *et al.* (2010) and Impel (2012)

As the chosen methods relate to a life cycle thinking perspective, it compromises the evaluation of emergency situations' environmental aspects, due to their inherent qualitative character, being extremely difficult of being quantified. If a risk analysis is not performed, the assessment will not represent correctly the environmental status of the organization and so, it will not consider the significance of the environmental aspects concerning accidents, such as spills or leaks.

As mentioned by Põder (2006), Moraes *et al.* (2010) and Impel (2012), the most effective way to measure the risk degree of a certain environmental aspect is by determining two distinct factors, the probability of occurrence and the possible environmental damage (severity), as stressed on the following formula:

$$\textbf{Risk} = \text{Probability} \times \text{Severity}$$

Põder (2006) addresses severity of the aspect as the combination of its magnitude (concentration of substances), spatial extent (physical area affected), temporal dimension (duration and persistence of the impact) and importance (value assigned to the aspect that might be set by political targets). Additionally, probability is addressed in frequency terms, that is, is assessed concerning the number of environmental accidents, causing impact on the environment, per year.

Moraes *et al.* (2010), addresses severity of the aspect with a five-point numerical scale that, basically, assesses both the spatial extent of the environmental impact (inexistence of environmental impact, environmental restrict to the local of occurrence, restrict to the company and, lastly, non-restrict to the company) and the persistence/reversibility of the impact, either with preventive measures or corrective ones. Additionally, probability is addressed on a ten-point numerical scale that ranges from a probability of occurrence lower than 10%, scored with 0 points, to a probability of occurrence between 90%-100%, being scored with ten points.

Impel (2012) addresses severity of the aspect by considering both the amount of the substance emitted and the distance and vulnerability of the surroundings (receptor vulnerability). Additionally, probability is addressed, not as frequency of occurrence but instead by considering factors such as attitude, compliance, EMS implementation and age of the installation, as they influence the risk of environmental accidents (either on a positive way, by decreasing the probability of occurrence as on a negative way, by raising the probability of occurrence).

4. Proposed methodology

4.1. Framework

Considering the whole existing literature, six papers were selected to have into account upon the development of an LCA based methodology to be applied in Continental Mabor.

In order to assess the quantifiable aspects, as well as the product's indirect stages, the papers written by Lewandowska (2011) and Lewandowska *et al.* (2011) were analysed and adapted with the purpose of being applied in the present study. Thereby, the stated aspects were assessed throughout the combination of environmental criteria (using ReCiPe as LCIA method up to the weighting step), legal criteria and stakeholder's perspective criteria.

However, qualitative environmental aspects cannot be evaluated using LCA. Thus, to assess these aspects, identified as nuisance and air emissions released under abnormal situations, was selected the qualitative method proposed by Gernuks *et al.* (2007) – ABC method. Notwithstanding, the criteria scale chosen to be applied was not the one suggested by Gernuks *et al.* (2007). Instead, to promote an evenly assessment, the applied numerical-scale was the one suggested by Lewandowska *et al*. (2011), combining, equally, legal thresholds and stakeholder's perspective. However, rather than using points (from the Lewanddowska *et al.* (2011) suggested numerical-scale), the ABC significance-scale was kept, making a correspondence between these points and letters (from ABC significance-scale, suggested from Gernuks *et al.* (2011)). So, letter A ("very important") corresponds to 3 points, B ("important") to 2 points and C ("less important") to only 1 point. Then, a combination of the two distinct criteria is performed, in order to reach the significance of the environmental aspects under evaluation. Annex 2 presents these multiple possible combinations.

In line with ISO 14001 specifications, a separate analysis had to be performed in order to identify the risks associated with the production process. For that purpose, Põder (2006), Moraes *et al.* (2010) and Impel (2012), addressed how to reach the procedure's risk degree. Thus, this specific analysis have taken the considerations of these authors into account and has been adapted in order to be easily applied in the case study organization, according to their data structure. The organization's documentation used to perform the present analysis include both "Environmental aspects identification and assessment" file (useful in assessing the environmental damage criteria) and the "Incidents 2013-2016" file (useful in assessing the probability criteria).

Bearing the above in mind, in this study it was established a numerical-scale to classify both the probability and the severity of the environmental aspects under study. Therefore, concerning the probability criteria and, according to the level of occurrence reported on the “Incidents 2013-2016” file, there were set three levels of scoring:

- Level 1 – “low probability”: Those, despite being mentioned as emergency situations’ aspects, have never really occurred, being referred to as an hypothesis, or have, on a temporal scale of four years, occurred only once;

- Level 2 – “moderated probability”: Those who have already occurred and have been reported two to three times during the last four years;

- Level 3 – “high probability”: Those who have occurred and been reported more than three times during the last four years.

In order to assess the severity and potential damage on the environment, the numerical-scale was adapted from the present methodology applied on the organization, referred to on sub-chapter 2.5 “Current methodology for assessing Continental Mabor environmental aspects”. Hence, it has in consideration the damage extension, the severity and the relative quantity of the aspect. Thus, as it has been already stated, the three-level scoring was determined on the following terms:

- The damage extension criterion is applied considering the following levels: local (1), regional (2) and global damage (3);

- The aspect severity is applied considering the following levels: generation of only non-dangerous and reusable waste (1), generation of non-dangerous and non-reusable waste, as well as effluents and emissions absent from legislation’s control lists (2) or dangerous waste generation, according to P 209/2004 (DRE, 2004), and effluents and emissions controlled by DL 236/98 (DRE, 1998) and SIDVA requirements, as well as P 286/93 (DRE, 1993) and 80/2006 (DRE, 2006), respectively (3);

- The aspect relative quantity is applied considering the following levels: released in lower values than those set by legislation or than those considered the typical values of the process step (1), is released in close values to those set by legislation or to those considered the typical values of the process step (2) or is released in higher values than those set by legislation or than those considered the typical values of the process step (3).

The final environmental damage value is the sum of the three parameters chosen to characterise it (extension value + severity value + relative quantity value). Applying these variables and summing them, a scale that ranges from 3 points to 8 points is obtained. In this scale, the aspects punctuated with points from 3 to 5 (included) are classified as “low severity”, those punctuated with 6 points have “moderated severity” and, finally, those punctuated with 7 and 8 points are classified with “high severity”.

By applying the formula suggested by Põder (2006), Moraes *et al.* (2010) and Impel (2012) - the product between probability of occurrence and the potential damage of a certain aspect in the environment equals its risk degree – a scale that ranges from 3 to 24 points is obtained. In this scale, the aspects scored with points lower than 14 (not included) should be consider non-significant emergency aspects, those punctuated between 14 and 18 (included) should be classified with a moderated significance and, lastly, those with points higher than 18 (not included) should be consider significant emergency environmental aspects.

Lastly, the results are presented as suggested by Gernuks *et al.* (2007), throughout a colourful matrix, distinguishing the relative importance of the environmental aspects by means of distinct colours: red for very important/significant aspects, blue for important/aspects of moderated significance and green for less important/non-significant aspects (Annex 5).

Figure 22 schematically presents the methodology proposed in this study, which combines a quantitative LCA-based assessment, a qualitative assessment and a risk degree analysis, allowing the evaluation of the whole framework of inputs and outputs related to the manufacturing process of a tire.

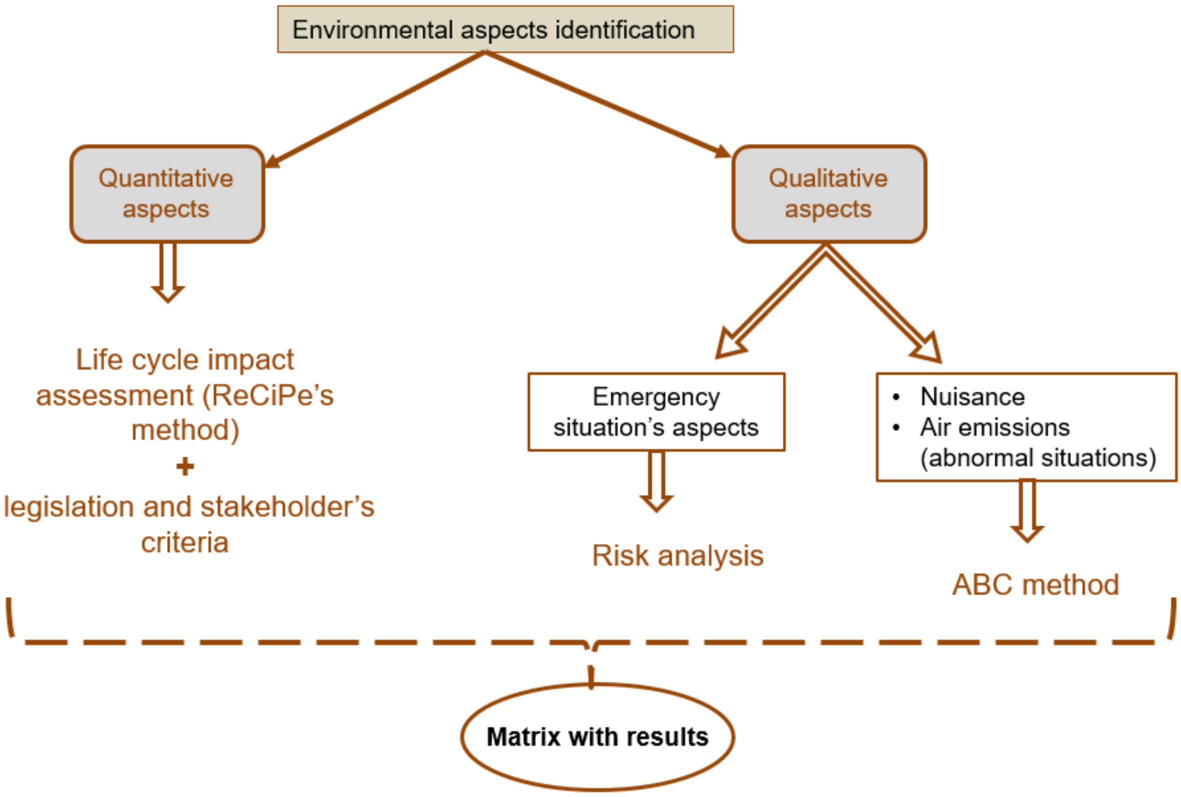


Figure 22. Representative flowchart of the proposed methodology steps.

4.2. Goal, scope and inventory analysis of the LCA study

To perform the LCA study, the typical LCA structure was followed according to ISO 14044:2006 and ISO 14040:2006 requirements and specifications (IPQ, 2008; IPQ, 2010), as described next.

4.2.1. Goal

The main goal of this study is, as far as possible, to evaluate the overall environmental impact derived from the mixing phase environmental aspects, always considering a life cycle thinking perspective, by evaluating the stages of resources extraction, transportation and end-of-life concerning the production generated among this phase. The foreseen results ought to be compared with the results obtained by the current methodology applied in the organization, hoping to prove the efficiency of the new proposed methodology, possibly improving the current environmental aspect's assessment performed by the organization.

4.2.2. Scope

The present method will allow the quantification and evaluation of the following environmental aspects (inputs and outputs): air emissions, waste generation, wastewater, and energy and resources consumption. It leaves aside environmental aspects with qualitative character, such as nuisance, air emissions under abnormal operation and environmental aspects from emergency situations, as accidental spills or soil contaminations, among other possible accidents responsible for causing environmental impacts. The whole framework of inputs and outputs was described, in detail, per stage of process, on sub-chapter 2.4 “Environmental aspects identification”, more precisely, on sub-chapter 2.4.1 “Mixing phase environmental aspects”. The present study, due to lack of data, will not assess on a quantitative way the stages respecting to the tire´s use phase and end-of-life management, ending the LCA assessment on the production’s waste management, performing a “cradle-to-gate” assessment, instead of a “cradle-to-grave” assessment (Figure 23).

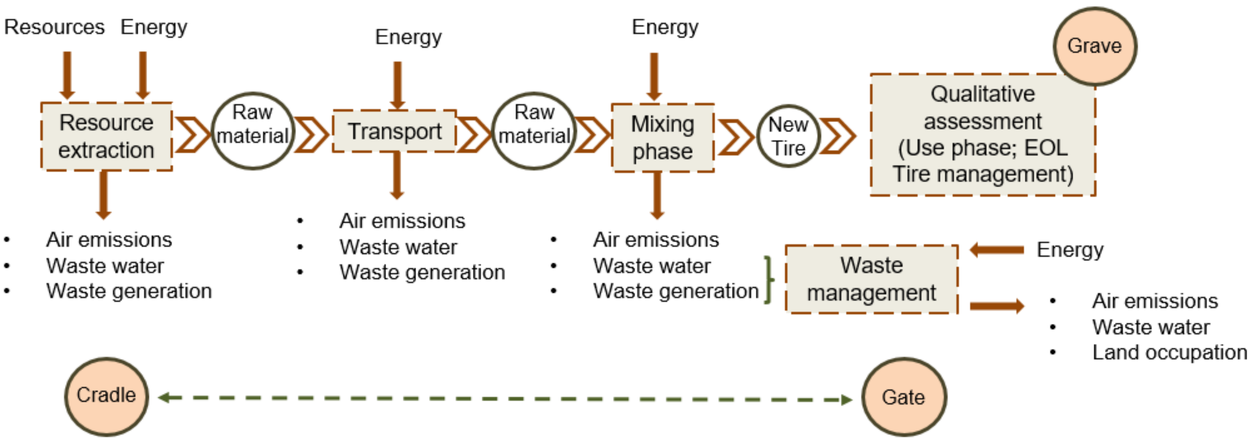


Figure 23. Flowchart representative of the framework of inputs and outputs taking in consideration during the assessment. Source: adapted from Continental AG (1999).

Therefore, the LCA will take into account the extraction of resources (only those consumed during the mixing stage), the rubber-compound production (mixing phase final product) and the end-of-life management of the waste generated during the other two stated stages.

The mixing process provides the rubber base-compound used, by means of extrusions, calendering and cutting, to form the elements which assembled and cured will afterwards form the tire. Hence, the chosen functional unit, to serve as reference during the assessment, was the amount of rubber-compound produced during year 2016 at the gate of the mixing process. Therefore, the whole data is collected and studied per year, being normalized towards this reference unit, considering a continuous labouring during 365 days, corresponding to 8760 hours. The functional unit was not considered the tire (overall final product) because the results would be misleadig, as the only phase from production considered in the present assessment was the mixing phase.

The analysed system is divided into foreground and background subsystems. The former, which is more specific and more detailed, is related with the mixing phase. In this case, primary data provided by the organization was used to perform the inventory analysis. The latter, more generic, is related with the indirect stages of production, including resources extraction, transport and end-of-life management, upon which the organization has no direct control, being merely capable of having some influence. Hence, in this case data was retrieved from scientific well known databases. For that purpose, Ecoinvent 3 (Frischknecht *et al*., 2007; Ecoinvent, 2017a) was mostly used and, only when no correspondence on this database was found is that others such as ELCD (ELCD, 2017) and Franklin USA 98 (Franklin Associates Ltd 98, 2013) were used instead. The latter was used with natural rubber input that has showed no correspondence among Ecoinvent 3. However, as this input consists of 35% of the whole rubber consumed it was unfeasible to neglect it. Moreover, the production and maintenance of capital goods was excluded from this study.

Within LCIA, the method chosen as more suitable according to the goal of this study was the ReCiPe method, according to the criteria suggested by JRC-IES (2010a) to select an LCIA method. These criteria include to always consider the most recent and update version and to take in consideration the completeness of the included elementary flows and coverage of impact categories, both on midpoint and on endpoint level. Furthermore, data uncertainties, regional validity and consistency of choices among the assessment are also important factors to consider.

Thus, ReCiPe is considered as one of the most reliable methods for evaluation, since it is one of the most recent and updated methods and it covers either midpoint as endpoint evaluations, presenting a strong consistency of principles, choices and mechanisms between impact categories and areas of protection. Besides, it presents a high completeness of elementary flows (about 3000 substances are considered and analysed) and impact categories (for midpoint it considers 17 impact categories, including climate change, ozone depletion, terrestrial acidification, freshwater and marine eutrophication, toxicity – human, freshwater, marine and ecotoxicity -, photochemical oxidant formation, particulate matter formation, land occupation and transformation, depletion of fossil fuel resources, mineral resources and water resource. For endpoint it considers human health, ecosystem quality/biodiversity and resources). Lastly, it provides normalisation factors for both midpoint and endpoint categories, as well as weighting factors for use on endpoint level and have a geographical representativeness concerning the European emissions and consumptions (Goedkoop *et al.*, 2013; JRC-IES, 2010a, Huijbregts *et al.*, 2017). ReCiPe method is, basically, an upgrade of Eco-indicator 99 and CML, by integrating a ‘problem oriented approach’ (CML) and a ‘damage oriented approach’ (Eco-indicator 99) (PRé Consultants, 2016b).

The possibility of using the Ecopoint method suggested by Gernuks *et al.* (2007) was also analysed, being scrutinize by JRC-IES (2010a) but, however not stated as being as reliable and adequate as ReCiPe. In addition of not being the most recent and update LCIA method, the data available on the software regards to Switzerland conditions. As this method is based on damage oriented methods and endpoint is characterized by policy targets, to apply it on Portugal would be less feasible.

Therefore, in order to calculate the contribution of each environmental aspect to the overall impact to obtain its significance by means of an LCA – SimaPro 8.2.3.0 has been used, by applying ReCiPe method (v112/Europe) – Hierarchist perspective (H). This perspective was chosen among two other possibilities: individualist perspective (I) and egalitarian perspective (E). The selection of this perspective is based on the recommendation of Goedkoop *et al.* (2013), who has stated that the hierarchist perspective is the most frequently used since it is based on the most common policy principles and it is a model with scientific consensus regarding to a 100 year timeframe. The significance of the aspects under evaluation will be determined by the weighting results.

4.2.3. Inventory analysis

As mentioned above, primary data provided by the organization was used for the assessment of the mixing phase. However, some assumptions had to be performed as it is stressed on Table 7.

Table 7. Assumptions performed per environmental aspect amongst this LCIA study.

Environmental aspect	Assumption
Air emissions	- Redrawn from the air emission's annual report; - Air emissions from abnormal operation were excluded from the LCA, due to their qualitative character; - The value considered to the whole group of mixing machines was an average of every sources measured, since they all have the same production capacity (i.e. the value pointed to the final mixing machines is an average performed with the measures from mixing machine 0, 1 and 3. Same is applied to master machines and OSM machines).
Waste	- Waste classified as raising from normal operation in fact account with waste generated both from normal operation as from emergency situations, due to lack of data regarding the latter; - The waste identified as being generated from mixing phase is a percentage, associated with an uncertainty rate, since the provided primary data only includes quantities from the whole organization.
Wastewater	- Wastewater was considered to be generated upon equipment maintenance (on abnormal operation) from bath stations - both from mixing machines and strainers; - Wastewater redrawn from UDSA (*Unidade Despoluidora de Solos e Águas*) was difficult to discriminate, being neglected on account of not being significant in comparison to the wastewater generated from the remaining industry; - The existing values regarding wastewater are, again, representative of the whole organization. Thus, the values used during LCA might be associated to some uncertainty rate.
Energy consumption	- Consideration of energy consumed amongst internal transportation (transportation by forklifts determined by the consumption of the corresponding batteries areas. Mixing phase is supplied by two full working areas), mixing and strainer's machines; - Chemical's automatic weight, carbon black storage on monthly silos, transportation system into daily silos, bath preparation and heating stations of liquid activators and liquid rubber stages were not accounted in the assessment, due to their lack of relevance towards the remaining organization consumptions.

As referred previously, data for the background system were taken from databases included in SimaPro and, in this case, some assumptions had also to be made. Regarding the production of the inputs considered during the mixing phase, the databases do not contain data for the production of some raw materials. Thus, some of them were simply classified as “chemical organics” or “chemical inorganics”, depending on the substance under assessment. Likewise, concerning the production of rubber there was an assumption performed for reclaim rubber. This input consists only of 7% of the total rubber consumed and has no correspondence in the current databases, hence, it was cut-off from the assessment.

The transportation of raw material into the organization has been taken into account by considering data provided by the organization, regarding the equipment type (maximum lorry weight), as well as the distance travelled, varying amongst the different suppliers. Conversely, data from the consumption of resources and emission factors regarding the transportation stage were also taken from Ecoinvent.

Waste disposal is a rather neglected part of life cycle inventories, and so, among this particular phase the recovery waste was cut-off of the assessment, on behalf of not having a properly classification on the inventory. It is possible to do so with no repercussions on the results due to the fact that the waste will become a new product, contributing to the decrease of waste production as well as resource consumption, and so their associated impacts are accounted for on the new product’s cycle (Ecoinvent, 2017b). Among non-recovery waste there are three distinct scenarios – carbon black, which was classified as inert material, being dispose on an landfill of inert substances; hazardous substances, regarding to chemicals and anti-tack bath solute waste which were considered to be disposed on underground deposits, on proper facilities and, lastly, wastewater treatment plant sludge which is dehydrated and then, disposed as hazardous substances, on underground deposits on proper facilities.

5. Results

With the purpose of comparing the ability to assess efficiently the significance of the environmental aspects under study, the following results encompass the two mentioned methodologies: the methodology currently applied at the organization (traditional based on multi-criterion) and the methodology proposed by this study (based on an LCA perspective).

5.1. Continental Mabor approach

With the application of the current organization's assessment methodology, based on criteria such as scale, quantification, severity and probability (as described in sub-chapter 2.5.) have showed significant environmental aspects in 4 stages of the mixing phase, among eight process steps. These stated results were reached by the organization itself and presented here to allow a comparison basis. Thus, they are represented in Table 8.

Table 8. Significant environmental aspects results, by using the current organization's approach.

Mixing process stage	Mixing process step	Significant Environmental Aspect	Operation Condition
Incoming, moving and unloading raw material	Unloading	Dangerous waste generation	Normal conditions
		Dangerous waste generation	Abnormal situations
		Air emissions	Abnormal situations
Storage and supply of silos and big-bags with raw material	Storage of carbon black in monthly silos	Air emissions Dangerous waste generation	Abnormal situations
	Storage in daily silos		
	Supply to the mixing machines		
Liquid activators and liquid rubber storage	Heating stations	Dangerous waste generation	Abnormal situations
	Supply to the mixing machines		

Mixing process stage	Mixing process step	Significant Environmental Aspect	Operation Condition
Mixing machines (Mezzanine)	Greasing	Dangerous waste generation	Normal conditions
	Cleaning		Abnormal situations

5.2. Proposed Methodology

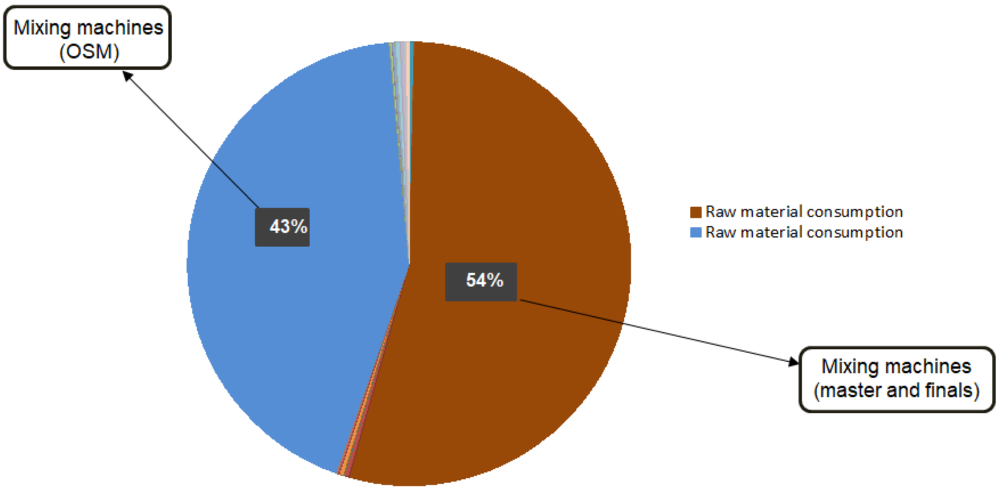
The methodology suggested in this study, as mentioned before, is based on LCA using weighting results for the environmental criteria, together with an evaluation concerning the legal compliance and the stakeholder's perspective and a risk analysis. The detailed classification of the whole framework of inputs and outputs is presented in annex 3 and 4, while in the following chapters only the main environmental aspects are presented.

5.2.1. Quantitative assessment

Environmental Criteria

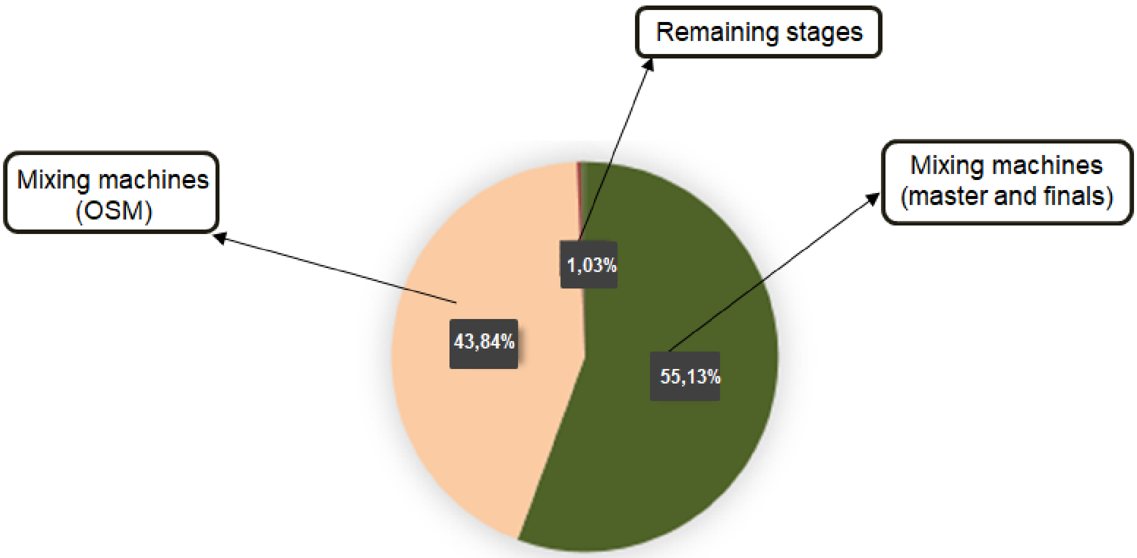
Regarding the environmental criteria, the highest score was obtained for the raw material consumption (with about 97% of contribution to the overall impact), due essentially to the impacts associated to its extraction and production, as well as to a small contribution of their transportation into the organization. Additionally, energy consumption was classified with a significant lower weighting value (about 2% of contribution), followed by air emissions, waste generation, wastewater and water consumption, all with less than 1 % of contribution to the overall impact.

Raw material is consumed mostly by mixing machines (finals/masters and OSM). Raw material consumed in finals/masters have a contribution of about 54% to the overall impact, being assigned with 3 environmental points, whereas raw material consumed in OSM machines present a contribution of about 43% to the overall impact, being assigned with 2 environmental points. This small discrepancy between the results is due to the fact that the OSM machines produce slightly less per hour than the finals and the masters. The remaining environmental aspects were classified with a much lower contribution to the overall impact, no more than 1% and, hence, assigned with 0 environmental points. Thereby, their evaluation is mostly performed throughout legislation compliance and stakeholder's perspective criteria. The results of this particular assessment are shown in graphic 3.



Graphic 3. Pie chart representing the distinct environmental impact contributions from the environmental aspects under evaluation.

When considering an assessment of the impact per stage, the mixing stage contributes with the highest share of the impact, being 43.8% assigned to the OSM machines and 55.1% to the master and final compound machines. The remaining share (about 1%) is assigned to the other stages of the process, such as incoming, moving and unloading raw material; storage and supply of silos and big-bags with raw material; small chemicals weighting; strainer; bath preparation and liquid activators and liquid rubber storage (Graphic 4).



Graphic 4. Pie chart representing the distinct environmental impact contributions from the mixing phase stages.

Legal regulation's criteria

Concerning legal regulation's criteria, the proposed numerical-scale was applied to the environmental aspects under study. The majority of the aspects were scored with only 1 point, as they are in compliance with the existing legislation. There were none environmental aspects evaluated with the maximum score (3 points), as none regulation is being broken. There are a few aspects, however, that were classified with 2 points, as they are at risk of legal contravention, mainly among mixing stage concerning the final's compound flow – on the following process steps: mixing and mills homogenization.

Stakeholder's criteria

The whole framework of inputs and outputs concerning this stage of procedure was classified with 1 point – "general interest exists", not existing records of any kind of complaint regarding these environmental aspects.

Significant environmental aspects

According to Lewandowska (2011) and Lewandowska *et al.* (2011) the environmental aspects classified as significant are those for which the sum of the aforementioned criteria (environmental + legal regulation + stakeholder) is equal to 3 or more points. Therefore, the aspects considered significant according to the present suggested methodology were: raw material consumption among the whole existing mixing machines, specially due to their high score among environmental criteria and air emissions released during final's compound mixing flow, specially due to legal compliance criteria. They are displayed in Table 9.

Table 9. Classification of the mixing phase environmental aspects, either on midpoint as on endpoint level.

Mixing process stage	Mixing process step	Environmental aspect	Significance (points)
Mixing machines finals and masters	Mixing	Air emissions	**3**
		Raw material consumption	**5**
Mixing machines finals and masters	Mills	Air emissions	**3**
Mixing machines OSM	Mixing	Raw material consumption	**4**

5.2.2. Qualitative assessment

In order to reach the whole framework of inputs and outputs was performed a qualitative assessment, related with legislation fulfilment, together with stakeholder's perspective (complaints records), by applying ABC method.

The only environmental aspect which, occasionally, generates complaints from the surrounding community is the nuisance, which were considered very important (A) upon the mixing and strainer stages, either from actual mixing as from mills homogenization steps. Upon the remaining stages is always considered less important (C), as the values are controllable towards legal limits and do not bother the surroundings (Table 10). The legal thresholds evaluated herein are the values set for day-evening-night equivalent level (Lden) and for night equivalent level (Ln).

Table 10. Nuisance aspect evaluation – ABC method.

Mixing process stage	Mixing process step	Complaints	Legal threshold	Importance
Incoming, moving and unloading raw material	Transportation to the Organization	**B**	**C**	Less important **(C)**
	Unloading raw material			
Storage and supply of silos and big-bags with raw material	Monthly silos storage	**B**	**C**	Less important **(C)**
	Transportation system into daily silos			
Mixing machines	Mixing and mills homogenization	**A**	**A**	Very important **(A)**
	Batch-off	**B**	**C**	Less important **(C)**
Strainer	Mills (strainer)	**A**	**A**	Very important **(A)**
	Batch-off	**B**	**C**	Less important **(C)**

Conversely, air emissions release on abnormal situations occurs among seven stages of the mixing phase: raw material unloading; monthly silos storage; transportation system into daily silos; daily silos storage; supply of big-bags facilities (with carbon black and silica) and small chemical's automatic weighting. There were identified very important environmental aspects (A) only amongst unloading of raw material and monthly silos storage of carbon black. The remaining assessed aspects have ranged from less important (C) to important (B), as shown in Table 11. The legal thresholds evaluated herein are the values set for the several emissions limit defined on P 286/93 (DRE, 1993) and on P 80/2006 (DRE, 2006).

Table 11. Air emission's aspect, reported on abnormal situations, evaluation – ABC method.

<table>
<tr><th>Mixing process stage</th><th>Mixing process step</th><th>Complaints</th><th>Legal threshold</th><th>Importance</th></tr>
<tr><td>Incoming, moving and unloading raw material</td><td>Unloading raw material</td><td>B</td><td>A</td><td>Very Important (A)</td></tr>
<tr><td rowspan="4">Storage and supply of silos and big-bags with raw material</td><td>Monthly silos storage (carbon black)</td><td>B</td><td rowspan="4">A</td><td>Very Important (A)</td></tr>
<tr><td>Transportation system into daily silos</td><td>C</td><td>Important (B)</td></tr>
<tr><td>Daily silos storage</td><td>C</td><td>Important (B)</td></tr>
<tr><td>Supply of big-bags facilities</td><td>C</td><td>Important (B)</td></tr>
<tr><td>Small chemical's weighting</td><td>Small chemical's automatic weighting</td><td>C</td><td>C</td><td>Less important (C)</td></tr>
</table>

Table 12 presents a matrix with the results, with the purpose of favouring an easier overview and comparison basis of the assessment and respective significant environmental aspects.

Table 12. Matrix regarding to the qualitative aspect's evaluation results – ABC method. Red square: very important (A), blue square: important (B) and green square: less important (C). Those not coloured are not representative of the process.

Mixing process step	Nuisance	Air emissions (abnormal operation)
Transportation to the Organization		
Unloading raw material		
Monthly silos storage		
Transportation system into daily silos		
Daily silos storage		
Supply of big-bags facilities		
Small chemical's automatic weighting		
Mixing and mills homogenization		
Mills (strainer)		
Batch-off (mixing machine and strainer)		

5.2.3. Risk analysis

Performing a risk analysis to assess emergency situation's aspects, such as leaks or spills – overall such as any non-predicted environmental aspect generation – is recommended by ISO 14001 certification, playing an important role both on preventive as on corrective measures, among the possible occurrence of environmental accidents. As so, going in line with authors such as Põder (2006), Moraes *et al*. (2010) and Impel (2012), it was applied a method with the purpose of reaching the risk degree of the environmental aspects associated with emergency situations, regarding the mixing phase of the production process.

In accordance with the chosen criteria, underlined on sub-chapter 4.1, there were none significant environmental aspects. This may be due to the fact that the data provided by the organization showed very few environmental accidents in the last four years, being, most of the aspects identified as hypothesis, having never really occurred. Hence, the probability has never been punctuated as high in any of the aspects. Conversely, in terms of environmental consequences when concerning relative quantity criteria they were always punctuated with the highest score, since as an accident it is expected that the environmental aspect is always generated in superior quantities, as it is, most of the times, an uncontrollable situation. Therefore, concerning the environmental consequence's criterion, the variables which promote variation between aspects are, in fact, the severity and the damage extension. The numerical-scale have always ranged from 5 to 8 points. The various possibilities of risk degree, concerning the variations on the set criterion scores are represented in Table 13, together with the setting significance scale.

Table 13. Classification chart of the risk degree associated to the organization's environmental aspects; red: significant, yellow: moderated significance and green: non-significant.

Prob x Conseq	5	6	7	8
1	5	6	7	8
2	10	12	14	16
3	15	18	21	24

Distributed throughout the stages of the mixing phase, there were identified 42 possible emergency situation's environmental aspects, as underlined on sub-chapter 2.4, which entails aspects such as: waste generation, air emissions, wastewater, fire situations and soil contamination. From those, none was considered significant, 5 were considered of moderated significance, due to their ability to cause higher damages on the environment and the remaining 37 aspects were classified as non-significant.

The aspects classified of moderated significance were identified on four stages of the mixing process, as presented on Table 14.

Table 14. Environmental aspects of moderated significance, by performing a risk degree assessment.

Mixing process stage	Mixing process step	Environmental aspect	Probability of occurrence	Severity of the aspect
Incoming, moving and unloading raw material	Oils incoming	Dangerous waste generation (oils)	Moderated	High

Mixing process stage	Mixing process step	Environmental aspect	Probability of occurrence	Severity of the aspect
Storage and supply of silos and big-bags with raw material	Supply of unloading bigbags facilities	Dangerous waste generation (chemical products)	Moderated	High
Storage and supply of silos and big-bags with raw material	Supply of unloading bigbags facilities	Air emissions (TSP)	Moderated	High
Mixing machines 0, 1, and 3 (finals)	Fire	Air emissions Dangerous waste generation Wastewater	Moderated	High
Mixing machines 2, 4, 5, 6 and 7 (Masters)	Fire	Air emissions Dangerous waste generation Wastewater	Moderated	High

5.2.4. Final results presentation

The results from the quantitative assessment plus the qualitative assessment and the risk degree were transferred for a matrix of results (annex 5), as proposed by Gernuks *et al*. (2007), favouring an easier overview of the significance of the whole framework of environmental aspects assessed. Thus, there are 11 significant/ “very important” environmental aspects, 9 environmental aspects of moderate significance/”important” and the remaining environmental aspects identified are considered non-significant/”less important”.

Table 15 presents the environmental aspects classified as significant and of moderated significance throughout the application of the suggested methodology. Thereby it may be considered environmental aspects worthy of consideration and attention during 5 stages – incoming, moving and unloading raw material; storage and supply of silos and bigbags with raw material; mixing machines (master, finals and OSM flows) and lastly, on strainer machines.

Table 15. Very important and important environmental aspects of the whole steps associated with the mixing phase.

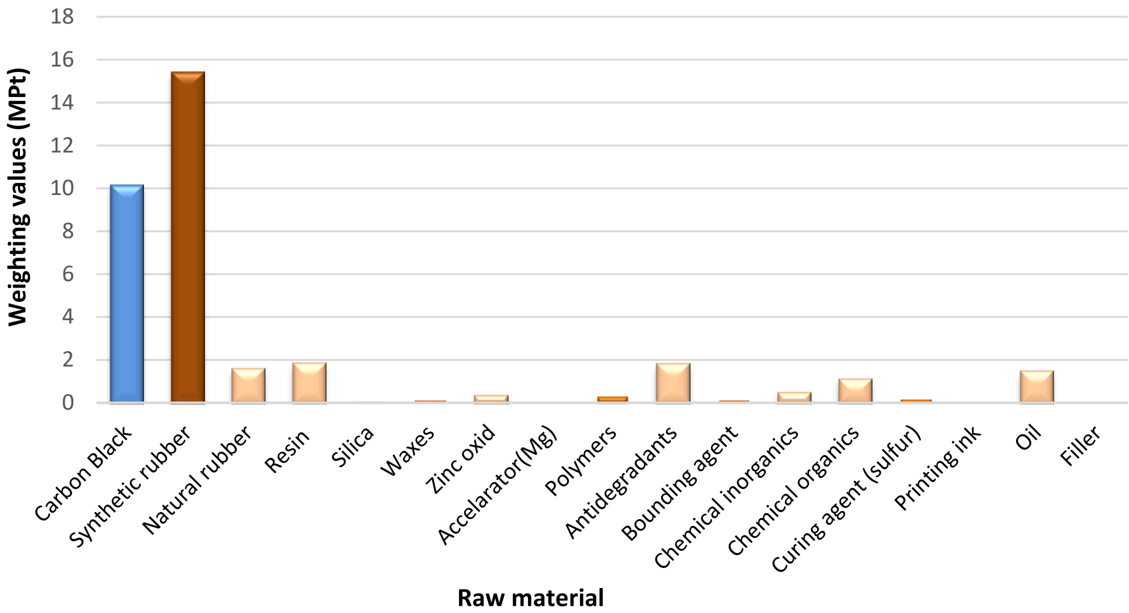
Mixing process stage	Mixing process step	Environmental aspect	Operation Condition	Significance
Incoming, moving and unloading raw material	Raw material incoming (oils)	Dangerous waste	Emergency	**Important**
	Unloading	Air emissions	Abnormal	**Very important**
Storage and supply of silos and big-bags with raw material	Monthly silos storage (carbon black)	Air emissions	Abnormal	**Very important**
	Transportation system to daily silos	Air emissions	Abnormal	**Important**
	Daily silos storage	Air emissions	Abnormal	**Important**
	Supply of unloading bigbags facilities	Air emissions	Abnormal	**Important**
			Emergency	
		Dangerous waste	Emergency	
Mixing machines (masters and finals)	Mixing	Raw material consumption	Normal	**Very important**
		Nuisance	Normal	
		Air emissions	Normal	
	Mills	Air emissions	Normal	
		Nuisance	Normal	
	Fire	Air emissions, dangerous waste and wastewater	Emergency	**Important**

Mixing process stage	Mixing process step	Environmental aspect	Operation Condition	Significance
Mixing machines (OSM)	Mixing	Raw material consumption	Normal	**Very important**
		Nuisance	Normal	
	Mills	Nuisance	Normal	
Strainer	Mills	Nuisance	Normal	**Very important**

5.3. Additional environmental evaluation

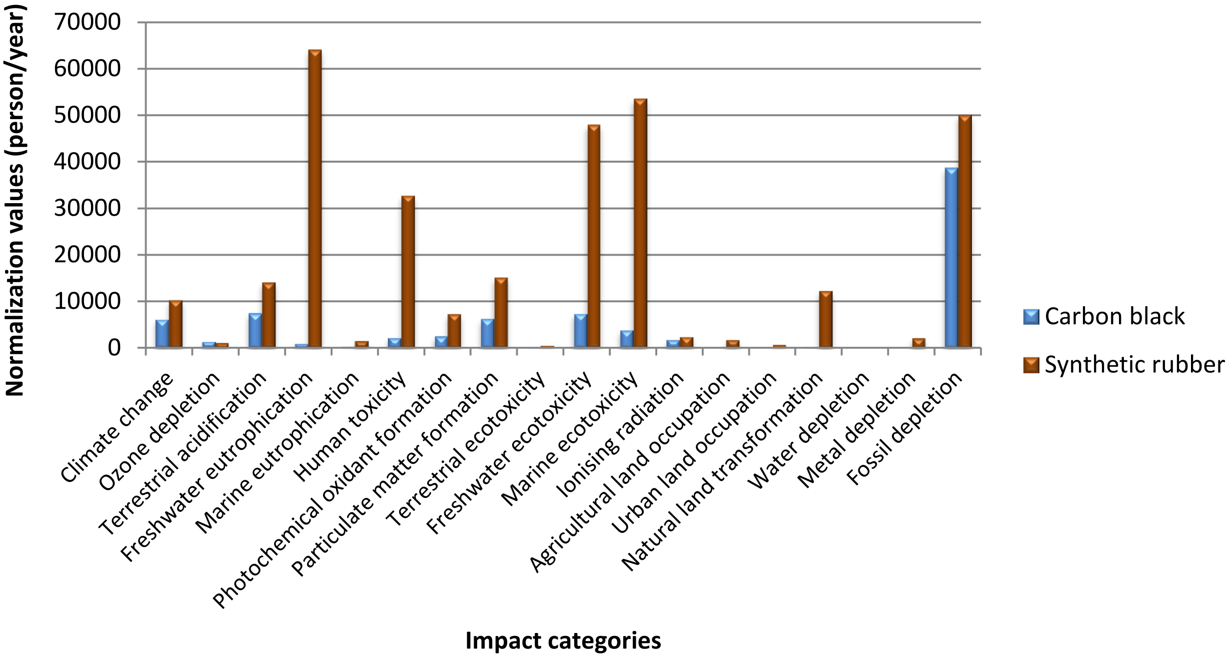
Concerning the mixing phase, the stage pinpointed as having the main contribution to the overall impact, was, undoubtedly, the stage regarding to the mixing machines, due to the broad list of raw materials consumed among the rubber's compound production. In order to better understand the origin of the stated environmental impacts associated with resources extraction and production, an additional environmental evaluation was performed by comparing the relative impacts of the different raw materials, which may be important for a latter decision regarding the application of control and mitigation measures.

The weighting results of the LCA using ReCiPe showed that the main raw materials responsible for the critical environmental impact were the synthetic rubber, with a contribution of 45% of the whole raw material impact and carbon black material, with a contribution of 29% of the whole raw material impact. The remaining 26% are evenly distributed throughout the other used materials, being slightly higher on natural rubber, resin, antidegradants and oils. These relative contributions are visible on graphic 5, where the weighing values assigned to the raw material consumed during the tire's production are represented.



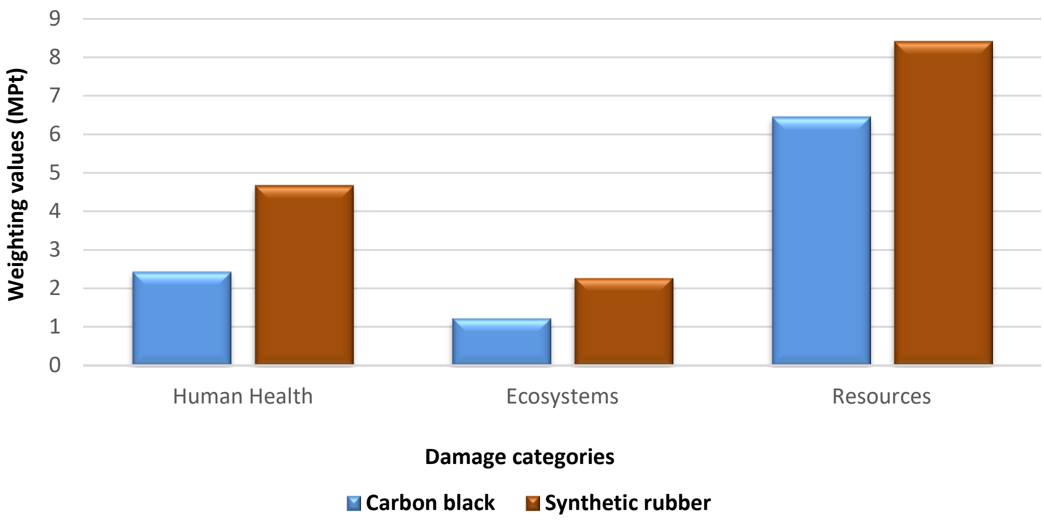
Graphic 5. Representation of the environmental impact associated with raw material consumption, by applying weighting step of ReCiPe.

Focusing the environmental assessment on the two most critical materials consumed, carbon black and synthetic rubber, it may be useful to understand which are the main environmental impacts occurring along the cause-effect chain, performing an evaluation with ReCiPe on midpoint level together with a normalization based on total European emissions/resource use per year (person/year). Hence, graphic 6 depicts the normalized impacts, on midpoint level, from carbon black and synthetic rubber consumption. Thus, it is visible that carbon black tends to have lower impacts than synthetic rubber in all the impact categories assessed by ReCiPe, with the exception for ozone depletion. Also, on the one hand, the impact categories which have presented larger differences between the two materials, showing dissimilar impacts on the environment were freshwater eutrophication, toxicity (human, freshwater and marine) and natural land transformation. Conversely, the impact categories which have presented minor differences between materials, showing similar impacts on the environment were climate change, ozone depletion, terrestrial acidification, ionising radiation, particulate matter formation, photochemical oxidant formation and fossil depletion.



Graphic 6. Comparative representation of the environmental impact associated with carbon black and synthetic rubber by applying normalization step of ReCiPe based on midpoint categories.

Other possible evaluation consists in understanding the environmental impact by using weighting step of ReCiPe with regards to the areas of protection affected by the materials under study. Therefore, on graphic 7 is visible the distinct contributions of the assessed raw materials into the pre-set areas of protection, assigning a higher importance to the environmental impacts concerning the resources category, followed by human health and lastly, among ecosystems diversity. Moreover the results presented a constant trend amongst the contribution of the assessed materials to the environment, as synthetic rubber has showed to have higher impact than carbon black in all the areas of protection under evaluation.



Graphic 7. Comparative representation of the environmental impact associated with carbon black and synthetic rubber by applying weighting step of ReCiPe .

5.4. Comparison between methods

The current methodology applied on the present plant serves as a representation of the results reached out by using a more traditional, multi-criterion type of methodology. The results presented on sub-chapter 5.1 “Continental Mabor approach” were reached by the organization itself and have already been implemented corrective actions, as well as control measures to deal with their significant environmental aspects. On the opposite side are the results reached out through the application of the present study’s proposed methodology, presented on sub-chapter 5.2.4 “Final results presentation”.

One major difference between the two methods remains on the fact that the case study organization applies the same method – one single group of criteria - to assess qualitatively the whole framework of aspects, making it difficult to adapt it to different aspects under different situations, possibly leading to distorted evaluations. Nevertheless, the uniformity inherent to this kind of approach enhances its application, by decreasing the associated complexity. On the opposite side, the proposed methodology makes that adaptation as per the aspect/operation condition under evaluation, thus distinguishing the assessment of quantitative and qualitative aspects.

The organization already pinpoints the several life cycle stages affected by the production of a tire, as well as the concerns inherent to these stages (as stated on sub-chapter 2.4.2.) not performing, however, a quantitative LCA method. Hence, the proposed methodology promotes the upgrade of this particular aspect, by classifying the environmental aspects according to the environmental impacts arising in every step of the product's cycle – on a cradle-to-gate perspective.

The organization, as according to the standard, already identifies the environmental aspects regarding to their work operation, analysing environmental aspects occurring both in normal operation and abnormal situations. Likewise, it performs the identification of every risks associated with their processes, assessing them on the same basis as the remaining aspects, hence non-considering their probability of occurrence, only associating them to possible accidental situations.

Another main difference is the consideration, on the qualitative assessment of the proposed methodology, apart from the legislation criteria – common to both methods – of the stakeholder's perspective, mainly concerning the presence of complaints, evaluating the disturbance of the surroundings.

These differences, to some extent, contribute to distinct results by reaching different significant environmental aspects among the mixing phase, as depicted in Table 16.

Table 16. Comparison between significant environmental aspects reached by the application of the two methodologies under study.

Mixing process stage	Continental Mabor approach results		Proposed methodology results	
	Mixing process step	Environmental aspect	Mixing process step	Environmental aspect
Incoming, moving and unloading raw material	Unloading	Dangerous waste (Normal)	None	
		Dangerous waste (Abnormal)	None	
		Air emissions (Abnormal)	Air emissions (Abnormal)	
Storage and supply of silos and big-bags with raw material	Monthly silos storage (carbon black)	Air emissions (Abnormal)	Air emissions (Abnormal)	
	Daily silos storage	Dangerous waste (Abnormal)	None	
	Supply to the mixing machines	Dangerous waste (Abnormal)	None	

Mixing process stage	Continental Mabor approach results		Proposed methodology results	
	Mixing process step	**Environmental aspect**	**Mixing process step**	**Environmental aspect**
Liquid activators and liquid rubber storage	Heating stations	Dangerous waste (Abnormal)	None	
	Supply to the mixing machines			
Mixing machines (Master and finals)	Mixing	Dangerous waste (Normal and Abnormal)	Mixing	Raw material consumption (Normal)
				Nuisance (Normal)
				Air emissions (Normal)
			Mills	Nuisance (Normal)
				Air emissions (Normal)
Mixing machines (OSM)	Mixing	Dangerous waste (Normal and Abnormal)	Mixing	Raw material consumption (Normal)
				Nuisance (Normal)
			Mills	Nuisance (Normal)
Strainer	None		Mills	Nuisance (Normal)

One of the main differences between the two methodologies is the evaluation of waste generation, because among the LCIA every environmental impacts associated with reusable waste were not considered (Ecoinvent, 2017b). It is common during this practice to do so (as explained above, on sub-chapter 4.2.3). Thereby, reusable waste generation were classified with zero points on the pre-set environmental scale, being only assessed through the complementary qualitative assessment – legal thresholds and stakeholder's perspective – ending with a somewhat lower level of importance ("less important") then when assessed through the organization's approach. The waste where the treatment was considered during the assessment (neither reused nor valorised) showed a very low contribution to the overall impact, when compared with other environmental aspects from the process.

The aspects considered significant by the proposed methodology are classified currently, by the organization's methodology, as aspects of moderated significance (being assigned with the highest score within this classification) and as aspects classified as significant (as in the case of air emissions release from raw material unloading step and carbon black storage on monthly silos). Also, those aspects considered "Important" aspects in the proposed methodology are equally classified as aspects of "moderated significance" by the organization, not presenting many differences on this level.

One final point regards to the environmental aspects quantifiable and hence assessed through LCA, that is, every aspects concerning normal operation, except for nuisance. The applied punctuation-scale only differentiates between significant/"very important" and non-significant/"less important", not having a midterm classification and hence not being comparable with the aspects classified as having "moderated significance" by the organization's method. Such classification would not matter in this particular case, since the assigned scale is so brief and the environmental contributions were significantly different, making a clear distinction between significant and non-significant.

6. Discussion

There is no doubt whatsoever that the prioritization of any organizations' environmental aspects represents one of the most crucial issues concerning their environmental performance. In a way, environmental managers should have a heightened awareness for the impacts associated with the whole product's cycle, on an extended producer responsibility perspective. In fact, identifying the significant environmental aspects concerning the organization's activities, products and services will strength the setting of an environmental policy with more specific commitments towards environmental goals and targets, aiming a continuous improvement of the environmental performance of any type of organization (Zobel *et al*., 2002; Ardente *et al*., 2006; Põder, 2006; Moraes *et al*., 2010 and Gajdzik and Wycislik, 2012).

Methodologies for environmental aspects assessment are implemented according to the requirements from the standard which the industry is certified by – on this particular case study, from ISO 14001 (IPQ, 2015). As the standard does not provide specific guidelines for the most correct way of assessing the significance of any organizations' environmental aspects, due to the enormous variety of organizations that it serves (Põder, 2006; Gernuks *et al.,* 2007), it is not possible to state which method under analysis is more correct. However, according to the existing literature on the subject, it might be possible to stress which is considered the most suitable method concerning the environmental principles and targets of the studied organization.

One of the current problems, referred by Zobel *et al.* (2002) and Gernuks *et al.* (2007) is the insufficient relevance placed on the environmental impacts, due to the qualitative and semi-quantitative character of the majority of the methodologies currently in practice, as shown by the survey performed by Lewandowska *et al.* (2013a, 2013b). The method suggested in this study seeks to develop a systematic, verifiable and reproducible assessment methodology capable of upset this issue. For that purpose, it may be stated that the quantitative character of the suggested method leads to an improvement towards the qualitative character of the currently applied methodology on the tire plant, by increasing its objectivity and hence lowering its inherent uncertainty rate.

Beyond being recommended on the latest ISO 14001 revision (2015) (IPQ, 2015), LCA is also referred, supported and studied by several authors. Despite the organization already demonstrates concerns on a cradle-to-grave perspective, it does not practice any LCIA method available, focusing the environmental assessment on the production process, on a gate-to-gate perspective, just like the majority of the current applied methodologies (Zobel *et al*., 2002; Lewandowska *et al*., 2013b; UNEP, 2015). However, the exclusion of the indirect environmental aspects related to its activities, products and services, as stressed by Zobel *et al.* (2002) and UNEP (2015), may lead to sub-optimisations.

Confirming the above, the present corporation has already performed an LCA study, where it has been proved that the manufacturing process is not the product's life cycle stage with the highest environmental impact. In fact, have been acknowledge that the use stage is the major responsible, with a contribution of more than 90% of the impact (Continental AG, 1999; Continental Global Site, 2016). These values prove the importance of having a life cycle thinking perspective when assessing the tire plant environmental aspects. The lack of control around these indirect aspects hinders their environmental management. Nonetheless, they should not be left out of the assessment and studies must keep spurring developments to reduce, as far as possible, the environmental impact inherent to this cycle's phase. Moreover, Lewandowska (2011) also refers the importance of assessing issues such as transport factors, practices of manufacturers and suppliers, extraction and distribution of raw materials and natural resources, waste management, among other aspects beyond the organization boundaries (indirect aspects).

Owing to the rising awareness regarding the concept of sustainability, LCA has becoming an active field of research, evolving steadily in the past decades (Hauschild *et al.*, 2013; Huijbregts *et al.*, 2017). In fact, since 2002 that UNEP/SETAC (United Nations Environment Programme/Society of Environmental Toxicology and Chemistry) have been making several efforts to enhance, promote and disseminate this practice along with industries' environmental managers, throughout an Life Cycle Initiative (Life Cycle Initiative, 2003; UNEP, 2004; Hauschild *et al.*, 2013). They have performed, in 2003, a survey which identified the need for transparency and scientific-based methodologies when assessing environmental aspects significance. Therefore, since then several reports and papers have been presented with different LCIA methods and hence different characterisation factors and representativeness of elementary flows, different impact categories and geographic representativeness coverage and several recommendations of results presentation, on attempting to simplify the further indicators interpretations for decision-making (Life Cycle Initiative, 2003; IPQ, 2010; JRC-IES, 2010a; Hauschild *et al.*, 2013; Hoof *et al.*, 2013). As ISO 14044 (LCA standard) is somewhat unspecific on guiding the practitioner choice (Life Cycle Initiative, 2003; Hauschild *et al.*, 2013), the reports and papers above mentioned have been very helpful in confirming the usability and the advantage of using ReCiPe method, along with weighting values to reach the significance of the environmental aspects under study.

The use of weighting values is somewhat controversial insofar as is the lesser scientific choice, being based on value judgements instead. In fact, ISO forbids its utilization among comparative assertions disclosed to the public (IPQ, 2010; Pre-sustainability, 2014; PRé Consultants, 2016a). However, in assessing environmental aspects in an EMS it allows the presentation of the results as single-scores which is acknowledge to be much more understandable for decision-making. Indeed, the latest efforts have been performed in order to simplify and improve the complex LCA results for decision-makers, who are almost never LCA practitioners (Life Cycle Initiative, 2003; Itsubo *et al.*, 2004; Lewandowska, 2011). The development of weighting values may be related to issues such as the relative importance of each impact categories for a pre-set panel, distance to target or monetary expression of the environmental impacts (present cost, willingness to pay, future extracting costs), being this latter the most used included in ReCiPe (Itsubo *et al.*, 2004; JRC-IES, 2011; Pre-sustainability, 2014; PRé Consultants, 2016a;). Furthermore, Zackrisson (2005) shows the efficiency of applying weighting values for assessing environmental aspects, serving as a reference for the methodology proposed in this study. Likewise, efforts for decreasing the number of indicators under evaluation have already been performed, throughout studies such as Jolliet *et al*. (2003), Jolliet *et al.* (2004) and Hauschild *et al.* (2013), who have tried to combine midpoint with endpoint evaluation, reducing the number of indicators from 17 to 3 areas of protection. Midpoint approaches (problem-oriented) have an associated lower rate of uncertainty, by strongly portraying the environmental flows. However, they have an inherent higher results complexity. Conversely, endpoint approaches (damage-oriented) have a higher rate of uncertainty but are much easier to interpret in terms of environmental relevance (Hauschild *et al.*, 2013; Huijbregts *et al.*, 2017). Thus, the suggested method under study is in line with the information mentioned above, as it assesses the environmental aspects based on weighting values applied on endpoint level, hence reducing the number of indicators under evaluation by using instead single-scores.

There are many authors pinpointing the criteria scale, severity, legislation and frequency (used by the organization) as effective criteria for assessing environmental aspects on a qualitative way. Examples of those authors include Põder (2006), Marazza *et al*. (2010), Gajdzik and Wycislik (2012) and Jan *et al.* (2012). Thus, there were a few details used from the current environmental management, as suggested to do so by Zobel *et al*. (2002) that refer it as a way of decreasing the initial workload associated with the

LCA assessment. Firstly the assessed aspects were the already identified by the organization. Secondly, the legislation parameter was very useful when applying the legal scale suggested by Lewandowska (2011) and Lewandowska *et al.* (2011). Thirdly, the combination of the scale, severity and legislation criteria were plainly used when assessing the environmental damage of the aspects rising from emergency situations and finally, the classification used around the waste generation (danger and respective treatment) was taken into account when characterising this particular aspect upon the application of the LCIA method.

Despite qualitative assessments being less recommended and pointed together with a few limitations of results, as Lewandowska et al. (2011) underlined, they are not supposed to be totally overridden by LCA methods with quantitative character, but yet combined due to the importance assigned to legal set thresholds, as well as the opinion regarding the interested parties (stakeholders) who cannot be assessed on a quantitative level. Examples of authors who addressed those two criteria include Zobel and Burman (2004), Põder (2006), Lewandowska (2011), Gajdzik and Wycislik (2012), USBR (2012) and SCCM (2014). Moreover, during the surveys performed by Joachimiak-Lechman (2013) and Lewandowska *et al.* (2013b) both legal compliance and stakeholders perspective are very popular among Sweden, Polish and Germany companies (countries under study), in a way that they proved that 40 to 100% of the companies studied used both when assessing, on a qualitative way, their environmental aspects. Besides that, the tire plant presents aspects that are not yet possible of being quantified such as nuisance, air emissions under abnormal operation conditions and environmental aspects rising from emergency situations. This raises the need of a complementary qualitative assessment, selecting for that purpose the ABC method which was chosen as suggested by Gernuks *et al*. (2007) and already been applied by several industries in Germany. Lewandowska *et al*. (2013b) performed a survey wherein has displayed that almost half of the industries analysed on Germany were using ABC method to assess their environmental aspects. The organization under study already identifies the environmental aspects regarding to their work operation, analysing either environmental aspects occurring among normal operation, as on abnormal situation. Likewise, it performs the identification of every risks associated with their procedures, assessing them on the same basis as the remaining aspects, hence non-considering their probability of occurrence, only associating them to possible accidental situations. The suggested method offers an improvement towards this issue, basing the assessment on already performed studies concerning this type of assessment, such as Põder (2006), Moraes *et al*. (2010), Gangolells *et al*. (2011) and

Impel (2012). This was, hence, the overall baseline for the formulation of the qualitative assessment from the methodology proposed.

The present study ought to demonstrate how a quantitative LCA-based methodology has the ability to improve the current environmental aspect's assessment performed on the organization and not to perform an identification and assessment of the organization's significant environmental aspects. Obviously that one of the major basis of comparison between the two methods is the difference between the significant environmental aspects reached out by each one of the methods – being its overall objective. In fact, the assessment performed throughout the proposed method has shown a few differences, mainly among inputs, waste generation and result's presentation structure. However, as the assessment is not the major goal, the results may present some uncertainty rate on account of the several assumptions performed (referred to on sub-chapter 4.2.3), data incompleteness and the use of European databases, not specific to the present product. Additionally, the fact that the study is being performed around only one production phase is not helpful for the certainty of the results. The overall environmental impact should, in fact, reflect the entire production process and the contributions of the several unit processes and included process steps should be calculated towards this value, thus making the assessment more realistic, as underlined by Zobel *et al*. (2002). They also stressed that, all in all, the main importance is the consistency of the LCIA results with the goal and scope of the study. On a further evaluation the assumptions performed can be tested during the sensitivity analysis, allowing an analysis of the data completeness and indicating if more work is necessary around a certain issue/aspect (Life Cycle Initiative, 2003; UNEP, 2015).

The adoption of an approach that combines qualitative and quantitative LCA-based assessments allows the evaluation of the whole framework of inputs and outputs according to their characteristics and specifications, contrarily to the application of a self-qualitative assessment, where the aspects are evenly assessed independently from their characteristics and/or operation conditions, which in some cases may lead to distorted results. Normally, this is mostly mentioned regarding input's assessments, which due to absence of legal regulation and difficulty on managing its associated environmental impacts, most of the times present little focus on their environmental relevance or might be simply omitted from the assessment (Lewandowska *et al*., 2011). In fact, this may explain the differences of the results regarding to the inputs under study, mainly concerning energy and raw material consumption. In the former, the only visible difference is among the differentiation between the energy consumed by forklifts during the material transportation and the energy consumed by the mixing and strainer machines which are considerably higher, despite being equally classified by the current methodology. The latter is significantly more important, as it is classified, by the suggested methodology, as the most relevant environmental aspect of the system under study. Raw material consumption is identified on two stages of the mixing phase (mixing stage, among final, master and OSM flows and on bath preparation stage). Organization's methodology assesses this environmental aspect with moderated significance on all the referred process stages where it is identified. Contrarily, the suggested methodology assesses the aspect as significant among the mixing stage, wherein are consumed the majority of the substances, and as non-significant among the bath preparation.

The scale selected to be applied on LCA method does not present a midterm classification and only classifies the aspects as significant/"very important" and non-significant/"less important", not presenting a comparison basis with those aspects classified as of moderated significance/"important aspects. Therefore, it was performed an attempt to uniform this significance-scale with the ABC method's significance scale, used on the qualitative assessment. However, it was unfeasible to compare both scales of significance in a way that it would possibly lead to a sub-optimization of the environmental relevance of the aspects under study.

The substitution of the presently applied methodology (more traditional, qualitative and semi-quantitative assessment) by the proposed methodology under study (quantitative LCA-based assessment combined with an qualitative assessment and a risk degree analysis) brings several advantages into the assessment and just a few limitations that are, according to Lewandowska (2011) and Lewandowska *et al*. (2011) not sufficient to disqualify it towards a more efficient environmental management. Therefore, it may be stated that the proposed methodology has enable the inclusion of quantitative information, raising the environmental focus of the impacts and regarding both direct and indirect environmental aspects, with respect to impact categories, wherein are included environmental issues on a global, regional and local scale. Furthermore, it provides a standardized method, supported by specific modelling softwares, and accepted by scientific community, allowing to reach more transparent, stringent, reliable, credible, objective (less dependent on the person/team work responsible for the assessment) and reproducible results. Moreover, as the matrix used for presenting the results is easily understandable it enhances the company acceptance by allowing a better decision-making. These characteristics are referenced as important criteria for measure efficiency by Zobel *et al*. (2002), Gernuks *et al.* (2007), Marazza *et al*. (2010), IPQ (2010), Lewandowska (2011) Lewandowska *et al*. (2011), Hauschild *et al.* (2013), Joachimiak-Lechman (2013), Lewandowska *et al*. (2013b) and PRé Consultants (2016).

On the other hand, it is true that the methodology proposed requires more time consumption (due to the higher number of environmental aspects under evaluation as not only assesses the direct aspects/gate-to-gate but also the indirect aspects/cradle-to-gate) and hence an higher effort (much more evident on the first assessment), higher costs (mainly related with software purchasing and employees training), higher complexity of assessment, despite the efforts performed to reduced it and finally, the lower uniformity inherent to the method as it would be more practicable to assess the whole framework of aspects on the same basis (as the organization does), however, LCIA method is not yet able to assess aspects with qualitative character. These verifiable limitations are acknowledged by Zobel *et al*. (2002), Lewandowska (2011), Lewandowska *et al*. (2011), Hauschild *et al.* (2013), Joachimiak-Lechman (2013) and Lewandowska *et al*. (2013b). Moreover, LCA still has a major space for improvement in order to be totally adapted to industries reality, mainly among inventory data completeness, characterisation factors definition and cause-effect chain modelling, particularly on wastewater treatment, waste treatment and on resources level (Hauschild *et al.*, 2013; PRé Consultants, 2016b; Huijbregts *et al.*, 2017).

The organization's approach, as a traditional and qualitative type of assessment, goes in line with the limitations pointed out by Lewandowska (2011) and Joachimiak-Lechman (2013) such as not being based on any impact models or supported by a standardized and scientifically accepted methodology, are instead performed on a generic and descriptive way, based on the knowledge and experience of an environmental manager, contributing to a higher subjectivity and lower reproducibility of results.

The differentiation between the two methodologies, according to the efficiency criteria mentioned above is displayed on Table 17.

Table 17. Comparison between the two methodologies studied regarding efficiency criteria mentioned in literature. (-): not efficient; (+):efficient and (++): very efficient.

Efficiency criteria	Continental Mabor Approach	Proposed Method
Assessment type	Qualitative/semi-quantitative	Quantitative + Qualitative
Assessment perspective	Gate-to-gate	Cradle-to-gate
Life cycle thinking perspective	Description of involved stages and concerns	Application of LCIA method
Number of used techniques	1	3

Efficiency criteria	Continental Mabor Approach	Proposed Method
Indication of work operation conditions	+	+
Environmental focus	-	+
Risk degree evaluation (considering probability of occurrence)	-	+
Transparency	+	++
Reproducibility	+	++
Subjectivity	++	+
Scientific acceptance	-	+
Geographical representativeness	+	++
Necessary expert knowledge/complexity of procedure	+	++
Time consumption/data requirements	+	++
Costs requirements	+	++
Understandability for decision-making	+	+

Concerning the significant environmental aspects identified by the application of the proposed methodology, there should be a closest attention in order to apply suitable measures. For that purpose it was performed an additional environmental evaluation, by using LCIA, to understand which are the most critical resources consumed. Therefore, the results from this detailed assessment, using weighting step, have shown that the most critical resources are the synthetic rubber with a contribution to the overall impact of 45% of the material consumed, followed by carbon black with 29% of the overall impact of the material consumed. Likewise, by assessing the distinct contributions of the addressed raw materials into the pre-set areas of protection, using weighting step, have been assigned a higher importance to the environmental impacts concerning the resources category, followed by human health and lastly, among ecosystems diversity.

With the purpose of analysing the whole cause-effect chain, attempting to reduce the level of uncertainty inherent to the first assessment due to the use of weighting values (as stressed by Huijbregts *et al.* (2017)), was performed an evaluation on midpoint level using normalization factors based on total European emissions/resource use per year (person/year). It was visible an overall trend that shows that carbon black presents lower environmental impacts than synthetic rubber in all the assessed environmental impacts (with the exception of ozone depletion). Furthermore, this trend was also visible on the assessment that used weigting values for evaluation of affected areas of protection, showing the higher environmental impacts caused by synthetic rubber. Hoof *et al.* (2013) underlined the importance of this step of evaluation by alerting to the fact that the use of single indicators may hide relevant environmental issues, being effective to evaluate on a more detailed way those aspects which proved to be more critical.

The above mentioned information is useful for the organization, in a way that evidence which resources measures should be applied on in order to decrease the associated environmental impacts. Concerning the most critical environmental aspect arising from the proposed methodology – raw material consumption – it is suggested that the organization replace the background used from generic European databases with data provided by the own suppliers (raising the certainty of data), improve its own manufacturing technology (in order to reduce the need for material input), carry out negotiations with the suppliers for them to modernise their manufacturing technology or to find others with better environmental performance and to consider the possibility of eliminating/replacing a certain material for one with lower environmental impact. These suggested measures are in line with the ones unveiled by Zobel *et al*. (2002) and Lewandowska *et al*. (2011). Despite the organization have no control upon third systems related to their products, they have the ability to influence their decisions (UNEP, 2015). Joachimiak-Lechman (2013) has referred that one of the organizations used to perform her study declared that LCA results are essential for decision-making when assessing suppliers behaviour, proving the particular importance of using this technique among inputs evaluation.

The qualitative assessment performed with the proposed methodology showed that there are also significant environmental aspects during unloading of raw material and carbon black storage among monthly silos. These two are equally considered significant by the organization, being already under control measures. Moreover nuisance from mixing and strainer machines were also identified as significant, being already under action plan. Air emissions among the master and final flow machines were also significant and are regularly controlled and have a working suction system.

Lewandowska *et al.* (2013a, 2013b) have performed a study to understand the level of methodologies acceptance and application among several industries on Sweden, Poland and Germany. They have underlined that nearly all the organizations used at least two techniques for assessing their environmental aspects, which recognizes the acceptability of using on the proposed methodology more than one method, in order to assess the whole framework of environmental aspects, instead of using the same method throughout the whole assessment, as characteristic from the organization. In fact, Liu *et al.* (2012), has presented a paper stressing the importance of combining quantitative LCA-based methods with qualitative assessments and risk degree analysis to reach the significance of environmental aspects. LCA is still barely used on the industry field among the environmental aspects assessment under an EMS, as was also displayed on Lewandowska *et al.* (2013a, 2013b) survey – only 21% of the Sweden organizations and 12% of the Germany organizations applied this practice among their environmental management. They referred as possible reason for this lower level of application by the organizations the accommodation to the most traditional qualitative and semi-quantitative assessments, having lack of preparation to understand and adopt different approaches, as is the case of the LCA (opinion also shared with Gernuks *et al.* (2007) and UNEP (2015)). There are example of industries that have already adopted LCA approaches to assess their environmental aspects, such as Stora Enso (Zobel *et al*., 2002) and Volkswagen (Gernuks *et al.,* 2007). The more organizations join this practice, the more it will evolve towards efficiency. Indeed LCA programme from UNEP/SETAC life cycle initiative even has as their own goal to stimulate collaboration between scientists and industrialists, in order to join together either practical as scientific challenges and thus leading to an easier and more suitable application of LCA (Life Cycle Initiative, 2003).

With the application of the proposed method, the results will represent the environmental aspects of an organization. Hence, the environmental goals and targets will be expressed as the intention of reduce the contributions to a certain environmental problem, instead of simply the intention of reduce the amount of a certain substance, which makes the interaction with the environment more obvious, favouring the environmental performance of the organization (Zobel *et al*., 2002; Lewandowska, 2011; Joachimiak-Lechman, 2013). Nevertheless, this particular tool (LCA), as underlined by Joachimiak-Lechman (2013), is somewhat versatile, allowing its application to any type of company, regardless of its activity, size, technology advancement, market position and ecological motivations.

7. Final considerations

On behalf of the latest concerns rising from the well-known concept of sustainability emerges the need for industrial organizations to adapt, as they are constantly looking for ways to improve their environmental performance. In this context, and in order to reach the environmental certification – either from ISO 14001 or from EMAS – the assessment of the environmental aspects became a crucial stage during the implementation of an EMS. Hence, it is quite easy to recognise the importance of studies that provide insights into methodologies capable of efficiently assess and thus prioritize the environmental problems associated to any organization, enabling to set environmental goals and targets, on a continuous improvement perspective.

Regarding the present case study, Continental Mabor is already certified by the new updated version ISO 14001:2015, presenting an already efficient qualitative, somewhat descriptive methodology to assess their environmental aspects. Hence, the goal was mainly focused on potential improvements, grounding bases on the most recent studies and recommendations made by specialists on this particular area. Nevertheless, the proposed methodology under study, despite being formulated according to the organization's specific data, is supposed to be reproducible on any kind of organization.

Even though the currently applied methodology fulfil the present needs, an EMS foster a continuous improvement and, as recommended by the updated standard ISO 14001:2015, organizations should adopt a more proactive behaviour and start taking into account life cycle thinking perspective when assessing their environmental aspects, respecting an extender producer responsibility by considering aspects either within as beyond the production system boundaries, or so called cradle-to-grave perspective. Moreover, another aspect many times mentioned in the literature is the relevance of increasing the environmental focus, by adopting more quantitative and objective methods. It is important to acknowledge the potential factors of improvement and start making changes towards a better environmental performance.

The proposed methodology provides a standardized and scientifically accepted method to assess environmental aspects, on a quantitative way, being able to provide reliable, stringent and reproducible results. Moreover, it assesses the risks associated to the production process as well as it considers legislation and stakeholders concerns associated to the identified aspects of the whole product's cycle. Besides that, it is considerably effective on decreasing the subjectivity inherent to the majority of the assessments currently applied on environmental aspects assessment. For all these reasons, the suggested methodology under study might be a suitable option for the present organization, as well as it proved to be a feasible solution for other companies to adopt it amongst their environmental aspects assessment, in order to reach more specific environmental goals and targets.

All in all, as LCA applied to environmental aspects assessment is somewhat recent and not yet often mentioned in the literature, a few limitations might be pinpointed, upon which further studies should focus on. There may be underlined potential improvement on the existing LCIA methods and completeness of databases, mainly among waste and water treatment inventories, characterised material’s inputs, coverage of the inventory flows and respective characterisation factors. Also, relevance should be given to studies on how to assess the environmental aspects not quantifiable in combination with the existing LCIA methods, enabling an evenly evaluation of the whole framework of inputs and outputs. One final limitation lay in the fact that the software used on this study (SimaPro) is currently paid, which may not be very appealing for organizations.

For a possible future application of the proposed methodology on the studied organization, it is suggested to overridden the cradle-to-gate perspective which has in consideration one single phase (mixing phase) of the whole tire production with a cradle-to-grave perspective which should have in consideration the whole value chain. By this means, the organization should take into account the contributions of the whole stages and unit processes to the overall environmental impact associated with tires’ manufacturing, allowing the industry to take actions and set goals towards those results. According to the feasibility of gathering the necessary data with all the requirements specified by LCA, the organization could, instead of performing an evaluation per unit process, assess the production phase as a whole and, towards the most critical results, perform more detailed evaluations.

For the purpose of improving this practice it is essential for organizations to start joining and start replacing the qualitative assessments on-site for quantitative assessments of the whole product’s cycle. The more it happens, the more it will improve towards efficiency. Thus, further studies on assessing environmental aspects on an industrial context based on LCA should be performed so that a stronger basis of knowledge around this subject is build up and environmental managers – who are normally not LCA practitioners – could understand the advantages that may arise from adopting this kind of methodologies.

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ANNEXES

Annexes

Annex 1. Multi-criterion assessment applied by the organization under study.

Environmental aspect	Scale	Value	Quantification	Value	Severity	Value	Probability	Value	Significance	Values
Air emissions	Local	1	Inferior to legislation set values	1	Others	1	in case of an accident or rarely	1	Despicable	4 to 6
			Closed to legislation set values	2	substances defined in *P*286/93 and P 80/2006	2			Moderated	7 to 8
			Higher than legislation set values	3					High	9 to 12
Wastewater			Inferior to legislation set values	1	Others	1			Despicable	4 to 6
			Closed to legislation set values	2	substances defined in *DL* 236/98 and SIDVA	2			Moderated	7 to 8
			Higher than legislation set values	3					High	9 to 12
Waste			Inferior to the typical values ofprocedure	1	non-dangerous and reusable waste	1			Despicable	4 to 6
			Closed to the typical values ofprocedure	2	non-dangerous, non-reusable waste	2			Moderated	7 to8
			Higher to the typical values ofprocedure	3	dangerous waste, according to *P* 209/2004	3			High	9 to 12
Soil contamination	Regional	2	Superficial damage	1	Inert products	1	periodically or occasionally	2	Despicable	4 to 6
			Phreatic surface damage	2	substances defined in *Decreto-lei* n.º 236/98	2			Moderated	7 to 8
			Unconfined aquifer damage	3					High	9 to 12

Environmental aspect	Scale	Value	Quantification	Value	Severity	Value	Probability	Value	Significance	Values
Water consumption			Inferior to the typical values ofprocedure	1	Is not scarce	1			Despicable	4 to 6
			Closed to the typical values ofprocedure	2	Is scarce	2			Moderated	7 to 8
			Higher to the typical values ofprocedure	3					High	9 to 12
Fossil fuels consumption			Inferior to the typical values ofprocedure	1	Renewable resource	1			Despicable	4 to 6
			Closed to the typical values ofprocedure	2	Non-renewable resource	2			Moderated	7 to 8
			Higher to the typical values ofprocedure	3					High	9 to 12
Energy consumption			Inferior to the typical values ofprocedure	1					Despicable	3 to 5
			Closed to the typical values ofprocedure	2	Non-aplicable				Moderated	6 to 7
			Higher to the typical values ofprocedure	3					High	8 to 9
Raw material consumption	Global	3	Inferior to the typical values ofprocedure	1	Non-dangerous resources	1	usually or on a continuously way	3	Despicable	4 to 6
			Closed to the typical values ofprocedure	2	Nocious resources	2			Moderated	7 to 8
			Higher to the typical values ofprocedure	3					High	9 to 12
Nuisance			Inferior to Lden and Ln legal values	1	Non-aplicable				Despicable	3 to 5
			closed to Lden and Ln legal values	2					Moderated	6 to 7
			Higher then Lden and Ln legal values	3					High	8 to 9

Annex 2. Punctuation scale – ABC method**.**

Legal threshold	Stakeholder's perspective	Significance
A	A	A
A	B	A
A	C	B
B	B	B
B	C	C
C	C	C

- Legal thresholds classified with "A" plus stakeholder's perspective classified also with "A" reaches an ultimately classification of "A" – very important aspect;
- Legal thresholds classified with "A" plus stakeholder's perspective classified also with "B" reaches an ultimately classification of "A" – very important aspect;
- Legal thresholds classified with "A" plus stakeholder's perspective classified also with "C" reaches an ultimately classification of "B" – important aspect;
- Legal thresholds classified with "B" plus stakeholder's perspective classified also with "B" reaches an ultimately classification of "B" – important aspect;
- Legal thresholds classified with "B" plus stakeholder's perspective classified also with "C" reaches an ultimately classification of "C" – less important aspect;
- Legal thresholds classified with "C" plus stakeholder's perspective classified also with "C" reaches an ultimately classification of "C" – less important aspect.

Annex 3. Application of LCA methodology.

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
Raw material incoming (oils)	Wastewater	Normal	0	3.89	0.0072	0	0	1	1	2
	Waste generation	Normal	0			0	0	1	1	2
Raw material incoming (Carbon black and silica)	Air emissions	Normal	0.3562			0.00065	0	1	1	2
Unloading	Air emissions	Normal	0.3562			0.00065	0	1	1	2
	Energy consumption	Normal	3.18			0.0058	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0.000623			1.14E-06	0	1	1	2
	Waste generation	Normal	0			0	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
Oil stored in monthly silos	Waste generation	Abnormal	0	3.99	0.0073	0	0	1	1	2
Carbon black stored in monthly silos	Energy consumption	Normal	3.18			0.0058	0	1	1	2
	Non-dangerous, non-reusable waste generation	Abnormal	0.00614			1.13E-05	0	1	1	2
Transportation system to the daily silos	Energy consumption	Normal	0			0	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
Daily silos storage	Waste generation	Abnormal	0			0	0	1	1	2
Daily silos supply	Waste generation	Abnormal	0			0	0	1	1	2
	Air emissions	Normal	0.3562			0.00065	0	1	1	2

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
supply of unload bigbags areas (carbon black and silica)	Air emissions	Normal	0.3562			0.00065	0	1	1	2
	Non-dangerous, reusable waste generation	Abnormal	0.00614			1.13E-05	0	1	1	2
	Waste generation	Abnormal	0.0819			0.00015	0	1	1	2
Small chemicals supply into production buffer	Non-dangerous, reusable waste generation	Normal	0	7.26	0.013	0	0	1	1	2
	Energy consumption	Normal	3.18			0.0058	0	1	1	2
Storagying buffer production with small chemicals	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Waste generation	Normal	0.928			0.0017	0	1	1	2
Bigbags substituiton	Air emissions	Normal	0.555			0.0010	0	1	1	2
	Waste generation	Normal	0.928			0.0017	0	1	1	2
Bins filling (manual weighting)	Air emissions	Normal	0.555			0.0010	0	1	1	2
	Waste generation	Normal	0			0	0	1	1	2
Small chemicals manual weighting	Air emissions	Normal	0.555			0.0010	0	1	1	2
	Energy consumption	Normal	0			0	0	1	1	2

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
Small chemicals automathic weighing	Air emissions	Normal	0.555			0.0010	0	1	1	2
	Energy consumption	Normal	0			0	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
Raw material transportation to the mixing machine (Final + Master)	Energy consumption	Normal	3.18	30005.8	55.13	0.0058	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
Mixing supply and actual mixing (Final + Master)	Energy consumption	Normal	186			0.342	0	1	1	2
	Air emissions	Normal	15.63			0.029	0	2	1	3
	Raw material consumption	Normal	29377			53.98	3	1	1	5
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Waste generation	Normal	0			0	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
	Wastewater	Abnormal	0			0	0	1	1	2
Carbon black recovery	Energy consumption	Normal	0			0	0	1	1	2
	waste generation	Abnormal	0			0	0	1	1	2
Mills homogenization (Final + Master)	Energy consumption	Normal	186			0.34	0	1	1	2
	Air emissions	Normal	15.63			0.029	0	2	1	3
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
Batch-off (bath, transportation, drying and palletizing)	wastewater	Abnormal	17.5			0.032	0	1	1	2
	Energy consumption	Normal	186			0.342	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Air emissions	Normal	15.63			0.029	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
Scrap	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
Rubber transportation for preparation area/ Storagying in ACS	Energy consumption	Normal	3.18			0.0058	0	1	1	2
Raw material transportation to the mixing machine (9,10 and 11)	Energy consumption	Normal	3.18			0.0058	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
Mixing supply and actual mixing (9,10 and 11)	Energy consumption	Normal	103			0.19	0	1	1	2
	Air emissions	Normal	12.5			0.023	0	1	1	2
	Raw material consumption	Normal	23501	23860.4	43.84	43.18	2	1	1	4
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Waste generation	Normal	0			0	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
	Wastewater	Abnormal	0			0	0	1	1	2

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
Calander extruder	Energy consumption	Normal	103			0.19	0	1	1	2
	Air emissions	Normal	12.5			0.023	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
Batch-off (bath, transportation, drying and palletizing)	Wastewater	Abnormal	6.56			0.012	0	1	1	2
	Energy consumption	Normal	103			0.189	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Air emissions	Normal	12.5			0.023	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
	Non-dangerous, reusable waste generation	Abnormal	0			0	0	1	1	2
Scrap	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
Rubber transportation for preparation area/ Storagying in ACS	Energy consumption	Normal	3.18			0.0058	0	1	1	2
Strainer: Mill supply	Energy consumption	Normal	3.18	381.40	0.70	0.0058	0	1	1	2
	Air emissions	Normal	0.00060			1.10E-06	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
Feeding mill/ Calender extruder/ Finishing mill (Strainer)	Energy consumption	Normal	186.92			0.34	0	1	1	2
	Air emissions	Normal	0.00060			1.10E-06	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Wastewater	Abnormal	0			0	0	1	1	2
Batch-off (bath, transportation, drying and palletizing) (Strainer)	Wastewater	Abnormal	4.376			0.008	0	1	1	2
	Energy consumption	Normal	186.92			0.34	0	1	1	2
	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
	Air emissions	Normal	0.00060			1.10E-06	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
	Non-dangerous, reusable waste generation	Abnormal	0			0	0	1	1	2
Solute transportation to the bath preparation station	Energy consumption	Normal	3.18	157.36	0.29	0.0058	0	1	1	2
Mixing	Energy consumption	Normal	0			0	0	1	1	2
	Water consumption	Normal	24.903			0.046	0	1	1	2
	Raw material consumption	Normal	126.096			0.232	0	1	1	2
	Wastewater	Abnormal	0			0	0	1	1	2

Process step	Environmental Aspect	Operation Situation	Weighing per aspect (KPt)	Weighting per phase (KPt)	Contribution per phase (%)	Contribution to the overall impact	Environmental Score	Legal regulations	Stakeholders	Significance
Supplying mixing tanks	Wastewater	Abnormal	0			0	0	1	1	2
	Energy consumption	Normal	3.18			0.0058	0	1	1	2
Production buffer storage (Liquid activators and liquid rubber storage)	Energy consumption	Normal	3.18	6.36	0.012	0.0058	0	1	1	2
Station supply (Liquid activators and liquid rubber storage)	Non-dangerous, reusable waste generation	Normal	0			0	0	1	1	2
Heating stations (Liquid activators and liquid rubber storage)	Energy consumption	Normal	0			0	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2
Raw material supply to the mixing machines (Liquid activators and liquid rubber storage)	Energy consumption	Normal	3.18			0.0058	0	1	1	2
	Waste generation	Abnormal	0			0	0	1	1	2

Total overall impact: 54,426.42 KPt.

Annex 4. Application of risk analysis. Green square: non-significant; yellow square: moderated significance.

Mixing Process Step	Environmental aspect	Probability	Severity	Probability x Severity	Significance
Transportation to the orgnixation	Soil contamination	1	6	6	
Internal transportation	Soil contamination	1	5	5	
Raw material incoming (oils)	Waste generation(oils)	2	7	14	
Raw mateiral incoming (carbon black and silica)	Air emissions	1	7	7	
	Waste generation (silica)	1	7	7	
	Waste genaeration (carbon black)	2	6	12	
Incoming, moving and unloading raw material	Fire	1	8	8	
			8	8	
			7	7	
Oil stores on monthly silos	Waste generation (oils)	1	7	7	
Supply of unload bigbags areas (carbon black and silica)	Waste generation (chemicals)	2	7	14	
	Waste generation (carbon black)	1	6	6	
	Air emissions	2	7	14	
Small chemicals supply into production buffer	Waste generation (chemicals and contaminated containers)	1	7	7	
Bigbags substitution	Air emissions	1	7	7	
Bins filling	Waste generation (chemicals and contaminated containers)	1	7	7	
Small chemicals manual weighting	Waste generation (chemicals and contaminated containers)	1	7	7	
Small chemicals automatic weighting	Air emissions	1	8	8	
	Waste generation (chemicals and contaminated containers)	1	7	7	
Raw material transportation to the mixing machine (0,1 and 3)	Waste generation (chemicals)	1	6	6	

Mixing supply and actual mixing	Waste generation (chemicals)	1	7	7	
	Air emissions	1	7	7	
Batch-off	Wastewater	1	6	6	
Mixing stage	Fire	2	8	16	
Rubber transportation to the preparation area/ storagying in ACS	Waste generation (cleaning waste)	1	7	7	
Raw material transportation to the mixing machine (2,4,5,6 and 7)	Waste generation (chemicals)	1	7	7	
Mixing supply and actual mixing	Waste generation (chemicals, oils)	1	7	7	
	Air emissions	1	7	7	
Batch-off	Wastewater	1	6	6	
Mixing stage	Fire	2	7	14	
Raw material transportation to the mixing machine (9,10 and 11)	Waste generation (chemicals)	1	6	6	
Mixing supply and actual mixing	Waste generation (chemicals)	1	7	7	
	Air emissions	1	7	7	
Batch-off	Wastewater	1	5	5	
Mixing stage	Fire	1	7	7	
feeding mill/Calender extruder/ finishing mill	Wastewater	1	6	6	
Batch-off (banho, transporte, secagem, paletização)	Wastewater	1	6	6	

Strainer	Fire	1	7	7	
Solute transportation to thebath preparation station	Waste generation (anti-tack, cleaning waste)	1	7	7	
Mixing	Waste generation (anti-tack, cleaning waste)	1	7	7	
Production buffer storage (liquid activators and liquidrubber storage)	Waste generation (chemicals, silane, cleaning waste)	1	7	7	
Heating stations	Waste generation (chemicals, silane, cleaning waste)	1	7	7	
Liquid activators and liquid rubber storage	Fire	1	7	7	
Scrap collection	Waste generation (cleaning waste)	1	7	7	

Annex 5. Matrix of result's presentation. Green square: non-significant/"less important" aspects; Blue square: moderated significance/"important" aspects and red square: significant/"very important aspects".

Environmental Aspect / Process step	Air emissions	Wastewater	Dangerous waste	Non-dangerous, reusable waste	Non-dangerous, non-reusable waste	Soil contamination	Water consumption	Energy consumption	Raw material consumption	Fossil fuels consumption	Nuisance
Transportation to the organization						Emergency				Normal	Normal
Internal Transportation	Normal					Emergency				Normal	
Raw material incoming (Oils)		Normal	Emergency Normal								
Raw material incoming (Carbon black and silica)	Emergency Normal		Emergency	Emergency							
Unloading	Abnormal Normal		Abnormal Normal	Normal				Normal			Normal
Fire associated to Incoming, moving and unloading raw material	Emergency	Emergency	Emergency								
Oil stored in monthly silos			Abnormal Emergency					Normal			
Carbon black stored in monthly silos	Abnormal				Abnormal						Normal
Transportation system to the daily silos	Abnormal		Abnormal					Normal			Normal
Daily silos storage	Abnormal		Abnormal								

Environmental Aspect Process step	Air emissions	Wastewater	Dangerous waste	Non-dangerous, reusable waste	Non-dangerous , non-reusable waste	Soil contamination	Water consumption	Energy consumption	Raw material consumption	Fossil fuels consumption	Nuisance
Daily silos supply	Normal		Abnormal								
supply of unload bigbags areas (carbon black and silica)	Abnormal Normal Emergency		Emergency Abnormal	Emergency Abnormal							
Small chemicals supply into production buffer				Normal				Normal			
Storagying buffer production with small chemicals			Emergency Normal	Normal							
Bigbags substitution	Emergency Normal		Normal								
Bins filling (manual weighting)	Normal		Emergency Normal								
Small chemicals manual weighting	Normal		Emergency					Normal			
Small chemicals automatic weighting	Abnormal Normal Emergency		Abnormal Emergency					Normal			
Raw material transportation to the			Emergency	Normal				Normal			

Environmental Aspect Process step	Air emissions	Wastewater	Dangerous waste	Non-dangerous, reusable waste	Non-dangerous, non-reusable waste	Soil contamination	Water consumption	Energy consumption	Raw material consumption	Fossil fuels consumption	Nuisance
mixing machine (0,1 and 3)											
Mixing supply and actual mixing (Finals and Masters)	Emergency Normal	Abnormal	Emergency Normal Abnormal	Normal				Normal	Normal		Normal
Carbon black recovery			Abnormal					Normal			
Mills homogenization (Finals and Masters)	Normal			Normal				Normal			Normal
Batch-off (bath, transportation, drying and palletizing)	Normal	Emergency Abnormal	Abnormal	Normal				Normal			Normal
Scrap				Normal							
Rubber transportation for preparation area/ Storagying in ACS			Emergency					Normal			
Fire associated to the mixing process	Emergency	Emergency	Emergency								
Raw material transportation to the mixing machine (9,10	Normal		Emergency	Normal				Normal			

Environmental Aspect Process step	Air emissions	Wastewater	Dangerous waste	Non-dangerous, reusable waste	Non-dangerous, non-reusable waste	Soil contamination	Water consumption	Energy consumption	Raw material consumption	Fossil fuels consumption	Nuisance
and 11)											
Mixing supply and actual mixing (9,10 and 11)	**Emergency**	**Abnormal**	**Emergency** **Abnormal** **Normal**	**Normal**				**Normal**	**Normal**		**Normal**
Calander extruder	**Normal**			**Normal**				**Normal**			**Normal**
Batch-off (bath, transportation, drying and palletizing)	**Normal**	**Emergency** **Abnormal**	**Abnormal**	**Normal** **Abnormal**				**Normal**			**Normal**
Scrap				**Normal**							
Rubber transportation for preparation area/ Storagying in ACS								**Normal**			
Fire associated to the mixing process	**Emergency**	**Emergency**	**Emergency**								
Strainer: Mill supply	**Normal**			**Normal**				**Normal**			
Feeding mill/	**Normal**	**Emergency**		**Normal**				**Normal**			**Normal**

Environmental Aspect / **Process step**	Air emissions	Wastewater	Dangerous waste	Non-dangerous, reusable waste	Non-dangerous, non-reusable waste	Soil contamination	Water consumption	Energy consumption	Raw material consumption	Fossil fuels consumption	Nuisance
Calender extruder/ Finishing mill (Strainer)		**Abnormal**									
Batch-off (bath, transportation, drying and palletizing) - strainer	**Normal**	**Emergency** **Abnormal**	**Abnormal**	**Normal** **Abnormal**				**Normal**			**Normal**
Fire associated to the strainer process	**Emergency**	**Emergency**	**Emergency**								
Solute transportation to the bath preparation station			**Emergency**					**Normal**			
Mixing		**Abnormal**	**Emergency**				**Normal**	**Normal**	**Normal**		
Supplying mixing tanks		**Abnormal**						**Normal**			
Production buffer storage (Liquid activators and liquid rubber storage)			**Emergency**					**Normal**			
Station supply (Liquid activators and liquid rubber storage)			**Emergency**	**Normal**							

Environmental Aspect Process step	Air emissions	Wastewater	Dangerous waste	Non-dangerous, reusable waste	Non-dangerous, non-reusable waste	Soil contamination	Water consumption	Energy consumption	Raw material consumption	Fossil fuels consumption	Nuisance
Heating stations (Liquid activators and liquid rubber storage)			**Abnormal**					**Normal**			
Raw material supply to the mixing machines (Liquid activators and liquid rubber storage)			**Abnormal**					**Norma**			
Fire associated to theLiquid activators and liquid rubber storage process	**Emergency**	**Emergency**	**Emergency**								
SCRAP collection			**Emergency**								